LEVEL II

1

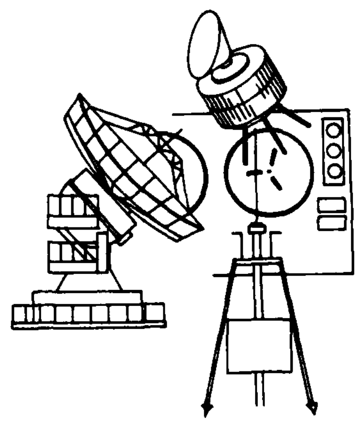
ARCTIC INSTITUTE OF NORTH AMERICA

1945

Concepts For Data Collections In The Arctic

Final Technical Report

May 1972



Prepared by

ARCTIC INSTITUTE OF NORTH AMERICA

1619 NEW HAMPSHIRE AVE., N.W.
WASHINGTON, D.C. 20009

ARCTIC INSTITUTE OF NORTH AMERICA

1619 New Hampshire Avenue, N.W.

Washington, D.C. 20009

CONCEPTS FOR DATA COLLECTION IN THE ARCTIC

(U)

FINAL TECHNICAL REPORT

By

J. A. Hatchwell, Principal Investigator

Prepared for

ADVANCED RESEARCH PROJECTS AGENCY--ARLINGTON, VIRGINIA

Contract N00014-70-A-0219-0003

Task No. 307-347

ARPA Order No. 1783

Scientific Officer, Ronald K. McGregor
Contract Effective Date, 1 May 1971
Contract Expiration Date, 30 April 1972
Amount of Contract, $78,260.00

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

The Arctic Institute of North America
1619 New Hampshire Avenue, N.W.
Washington, D.C. 20005

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

N/A

AD-A085 970

3. REPORT TITLE

6 Concepts for Data Collection in the Arctic.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

9 Final Technical Report.

5. AUTHOR(S) (First name, middle initial, last name)

10 Joseph A. Hatchwell

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
11 May 1972	72	28

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
15 N00014-70-A-0219-0003, ARPA Order-1783	None 12 78
b. PROJECT NO. 307-347	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) None
d.	

10. DISTRIBUTION STATEMENT

Unlimited Distribution

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	Advanced Research Projects Agency

13. ABSTRACT

This report identifies, describes, analyzes, and evaluates new concepts for collecting and processing data and information gathered above, on, and under sea ice and contiguous land areas of the Arctic Basin, including manned and unmanned systems of varying sizes with both short-term and long-term operations.

033050

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Arctic Radio Communications						
Data Processing in Arctic						
Arctic Research Platforms						
Sensor Development for Arctic Use						

CONTENTS

FIGURES

TABLES

SECTION I

INTRODUCTION

The Arctic Institute of North America's original proposal to the Advanced Research Projects Agency (ARPA) called for a study effort which would investigate system feasibility concepts for use in the Arctic that would incorporate current remote sensing digital and information retrieval techniques. Because of budgetary constraints, however, ARPA requested that the scope of the originally proposed study be reduced. Accordingly, the Arctic Institute submitted a new plan which ARPA approved. This plan spelled out a program that would identify, describe, analyze, and evaluate new concepts for the collection of data and information above, on, and under the sea ice and contiguous land areas of the Arctic Basin, including manned and unmanned systems of varying sizes with both long-term and short-term operations. This report presents the results of this study.

In addition to identifying system concepts, the report discusses scientific and technological advances that could serve usefully if adapted to arctic research efforts. Areas covered in the report include (1) radio communications and the blackout problems caused by solar disturbances; (2) technological progress in data communications and automatic data processing that has resulted from the national space effort; (3) developments in electronic components; (4) computers as a means of processing and storing great volumes of data; and (5) platforms from which scientists could more easily acquire and record data.

In connection with platforms, the study turned up the air cushion vehicle. Used as a mobile platform, this vehicle holds great potential for scientific work throughout the Arctic Basin. This fact was pointed out to the Office of Naval Research, Polar Programs. As a result, this program was altered to allow an investigation of the potentials of the air cushion vehicle. The results of this effort are contained in a separate report "A Feasibility Study of an Integrated Mobile Data Collection Platform Using an Air Cushion Vehicle," by J. A. Hatchwell and R. A. Lenton of the Arctic Institute of North America.

Acknowledgment

During this study, the author was fortunate to have access to advisors in scientific research data system design and arctic environment logistic support. Acknowledgment is expressed for the support given by the following individuals:

Dr. N. Untersteiner, AIDJEX Program Director

Mr. W. Wittmann, OCEANO, U.S. Navy Polar Programs

Mr. E. Ehrlich, NASA Headquarters, Communications Planning

Mr. E. Painter, NASA Goddard, ERTS Program

Mr. R. Rochelle, NASA Goddard, Space Telemetry

Dr. F. Roots, Department of Energy, Mines and Resources

Dr. A. Assur, Cold Regions Research and Engineering Laboratory

Mr. A. Malloy, USNUSRL, San Diego

Mr. G. Kenny, Communications Task Force Coordinator, Man in the North Project, Arctic Institute of North America

Mr. D. Loftus, Office of Canadian Telecommunications

Mr. J. Huffman, Engineer, Office of Polar Programs, National Science Foundation

Dr. K. Hunkins, Lamont-Doherty Geological Observatory

In addition, the author wishes to thank Mr. R. C. Faylor, Director, Washington Office of the Arctic Institute of North America, for his timely suggestions and encouraging support.

SECTION II

CONCLUSIONS AND RECOMMENDATIONS

Estimates of arctic scientific data growth over the next 5 years indicate that the digital flow traffic should not exceed $1x10^8$ bits per day. Narrowband communication networks capable of passing up to 2400-bit-per-second digital data streams will satisfy this transmission requirement.

The long-term system design goal should be to completely automate the data acquisition and processing cycle, particularly field components. This should greatly reduce the high cost of housing personnel and field laboratory support. In addition, an automated acquisition facility offers greater potential for year-round operations.

Meteorologic and oceanographic instrument development has failed to keep pace with solid-state component and circuit technology. Some industry manufacturers hesitate to commit in-house development for arctic needs due to the limited demands for such products and to the substantial dollars required for research. Federal R&D funding support is recommended in the following areas:

- Integrated remote automatic sensing arrays.
- Sensor for automatically identifying and classifying sea ice conditions.
- Long-life, economical, unattended electric power sources in the 800-watt to 1-kilowatt range.
- Remote sensor platform development.

Among arctic investigators, there is growing concern for an improved system of data acquisition and retrieval. A full-time data manager should be appointed to control and regulate the inflow and outflow of data through the entire collection system. In addition, a data coordinator should be assigned to the staff of each major scientific project to ensure that useful data are collected and rapidly interfaced into the central processors of the system.

While polar satellites appear an attractive technical solution to the problem of rapid data collection and retrieval, they involve high capital investments. Unless the satellites can be equipped as multi-function platforms for sensing and communication relaying, they would not be competitive with existing narrowband data acquisition systems.

The search for long-life platforms from which sensors can be deployed and from which data can be collected on a year-round rather than on a seasonal basis is a continuing effort in the Arctic. This study identified the air cushion vehicle, which appears suited for field scientific data collection missions. This is an all-season vehicle that would permit many types of work to be carried out at almost any time of the year.

SECTION III

ARCTIC ENVIRONMENT

In this report, the Arctic Basin is defined as that area surrounding the North Pole. Included in this area are the Arctic Ocean and its seas, the many water passages that connect the Arctic Ocean with the Atlantic and Pacific oceans, and adjoining land areas with continuous permafrost. (See Figure 1.)

The environment presents the greatest challenges to scientists who conduct research in the Arctic Basin. The following discussion relates some environmental factors that profoundly affect both scientists and the equipment they use to conduct research.

Sea Ice

Sea ice rarely forms in the open ocean below 60°N, but it may drift far south of this latitude. Between 60°N and 75°N, the occurrence of sea ice is a seasonal matter, and there is usually a period of the year when the water is ice free. Above 75°N, there is a more or less permanent ice cover. (See Figures 2 and 3.) Even in winter, however, the Arctic Ocean is never totally ice covered. A recent estimate, based on infrared temperature measurements, is that as much as 10 percent of the Arctic Ocean is either open water or thin ice over refrozen leads.

There is little accurate data on the height and frequency of pressure ridges in the Arctic Ocean, but heights of 26 to 33 feet are occasionally seen and heights of 13 to 16 feet above the average ice surface are common. To date, it has not been possible to determine a roughness coefficient. The number of pressure ridges per mile may vary from 0 to 60 or more. Because of its density, uniform sea ice floats with 87 percent of its volume below sea level. When a pressure ridge is formed it tends to sag or slump because of the plasticity of ice.

From data obtained by the U.S. Navy's Project Birdseye and from the upward-beamed acoustic data obtained during the 1957 through 1962 under-ice cruises of submarines, the arctic pack ice has no consistent thickness. Constant fracturing, diverging, and compacting motions result in a spectrum of thicknesses ranging from a few inches to more than 15 feet. The data further indicate that the ridges and hummocks, whose drafts may average 40 feet in summer and 55 feet in winter, contribute significantly to the total ice volume. On rare occasions sea ice ridges may attain a thickness of 200 feet. The general movement of ice in the Arctic Ocean is shown in Figure 4.

Open Water Zones

Coastal configurations, especially geographic obstructions in the path of moving ice, profoundly affect sea ice distribution. The famous "North Water," which in midwinter occupies an area of 4,000 square miles and is recurrently

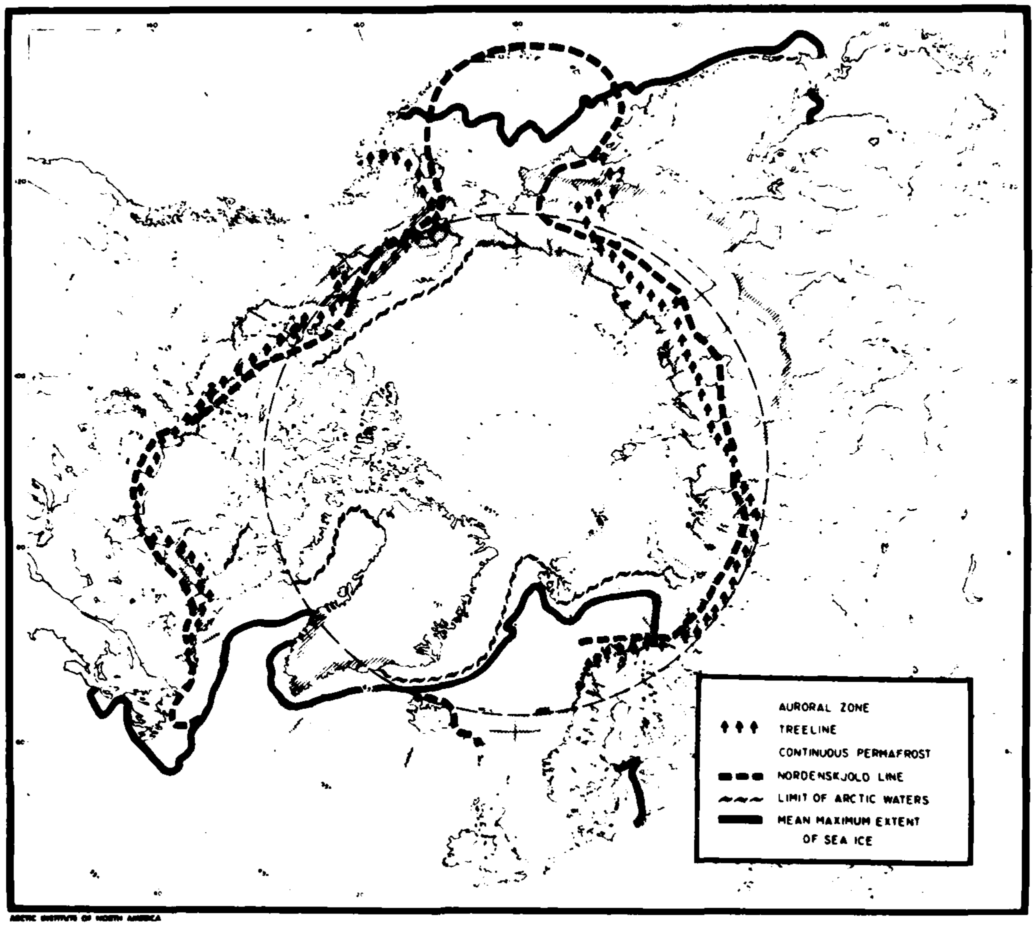


Figure 1. SOME SIGNIFICANT BOUNDARIES IN THE ARCTIC REGION

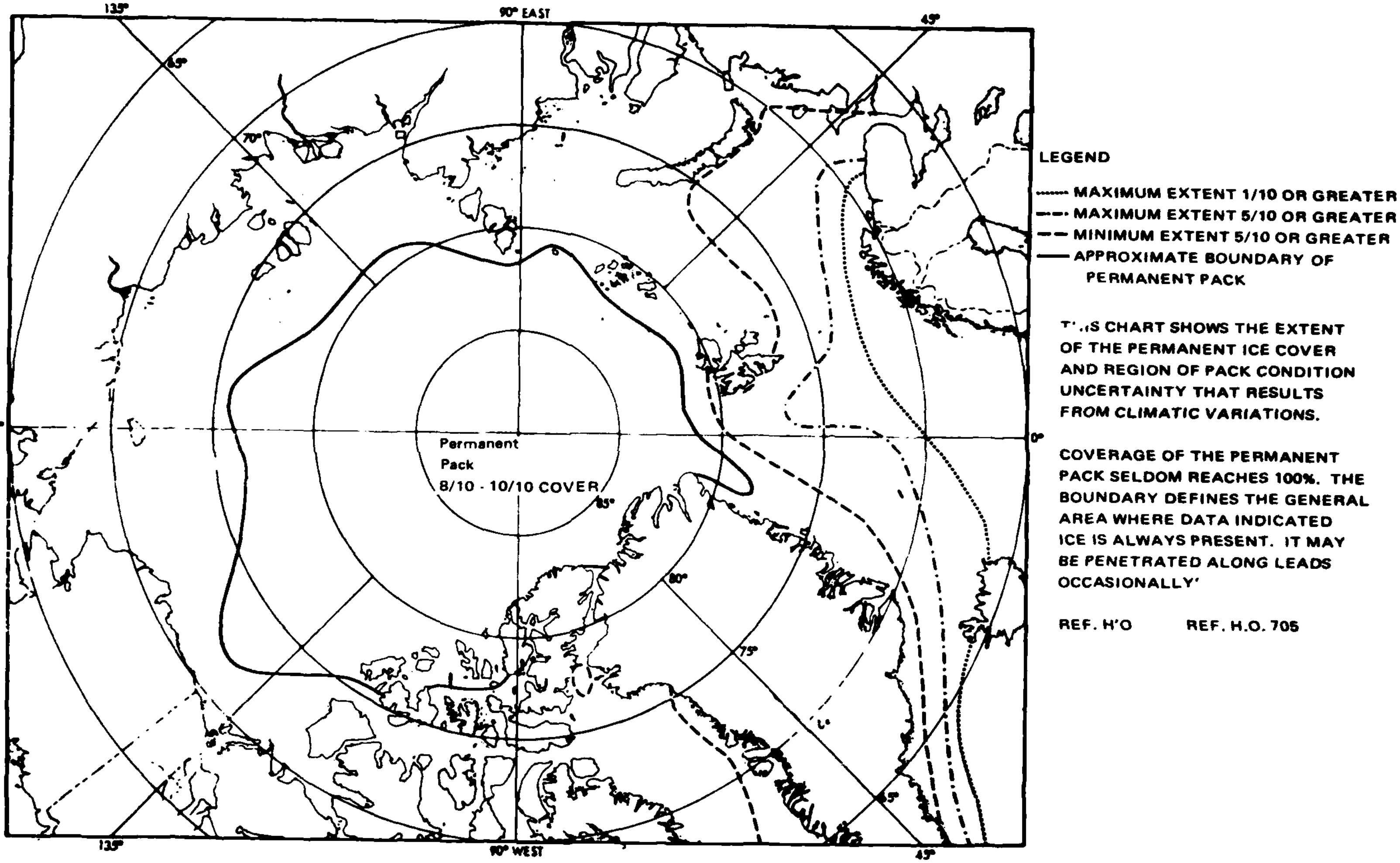
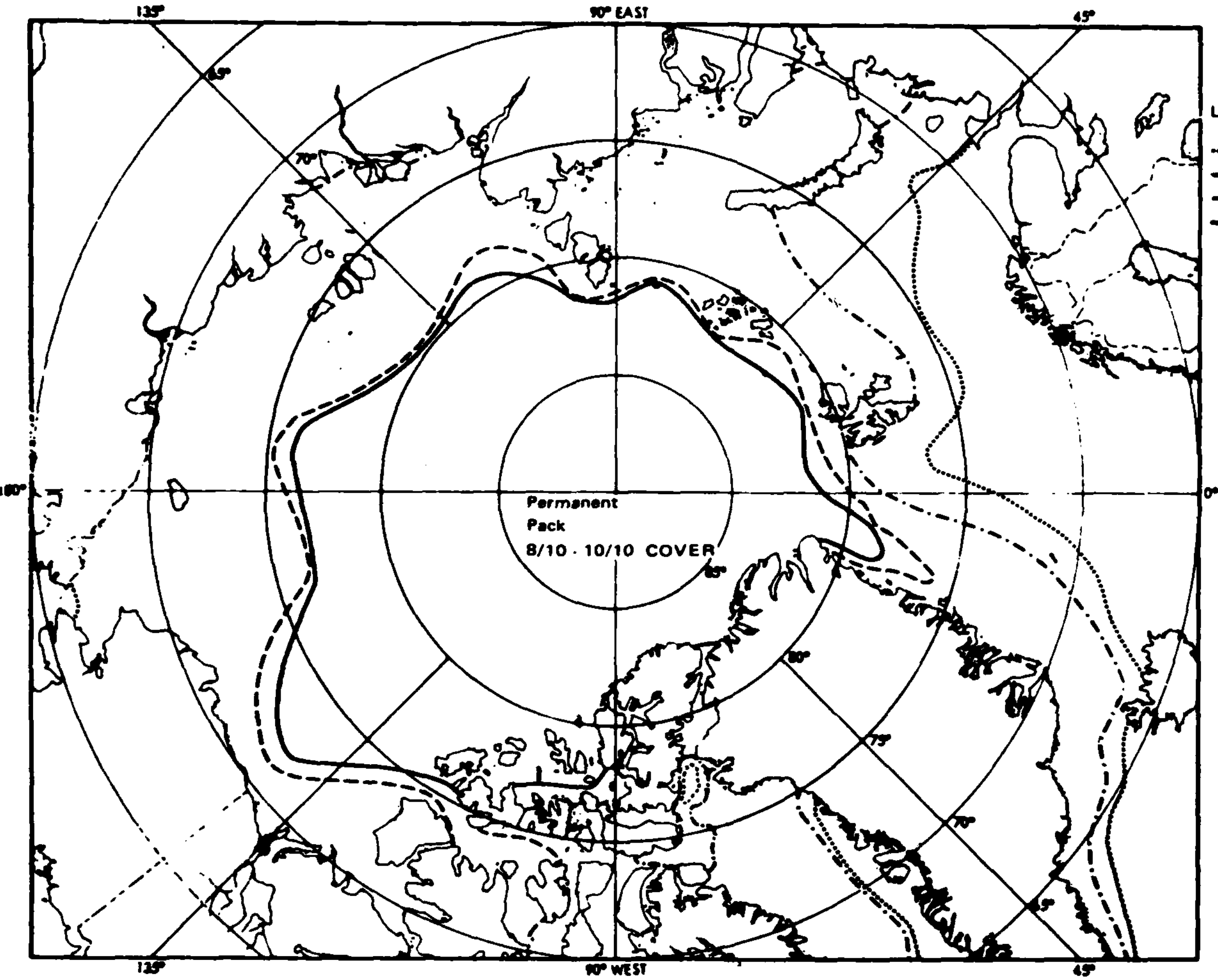


Figure 2. Extent of Pack Ice in Winter



LEGEND

- MAXIMUM EXTENT 1/10 OR GREATER
- MAXIMUM EXTENT 5/10 OR GREATED
- MINIMUM EXTENT 5/10 OR GREATER
- APPROXIMATE BOUNDARY OF PERMANENT PACK

THIS CHART SHOWS THE EXTENT OF THE PERMANENT ICE COVER AND REGION OF PACK CONDITION UNCERTAINTY THAT RESULTS FROM CLIMATIC VARIATIONS.

COVERAGE OF THE PERMANENT PACK SELDOM REACHES 100%. THE BOUNDARY DEFINES THE GENERAL AREA WHERE DATA INDICATES ICE IS ALWAYS PRESENT. IT MAY BE PENETRATED ALONG LEADS OCCASIONALLY.

REF. H.O. 705

Figure 3. Extent of Pack Ice in Summer

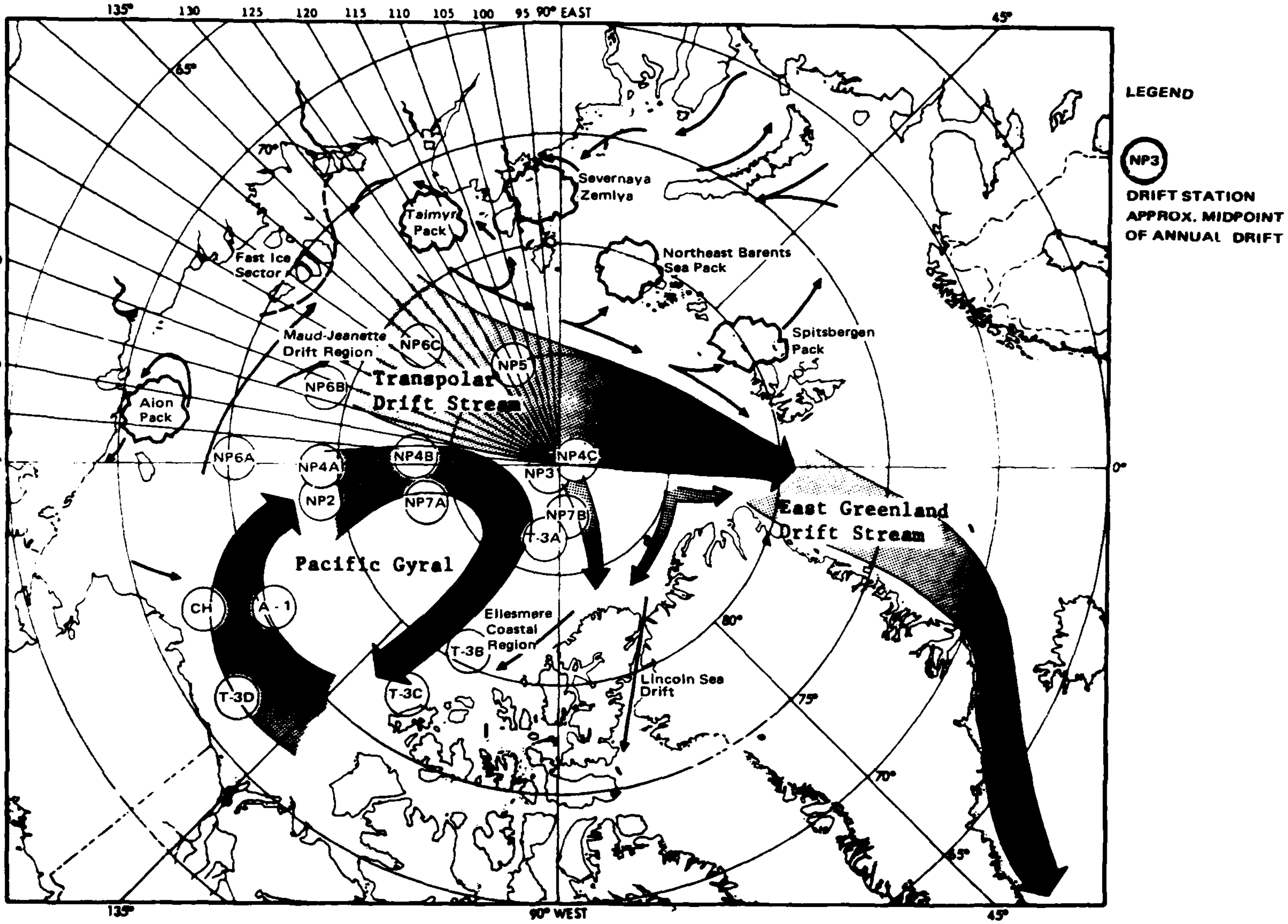


Figure 4. General Movement of Pack Ice

found in northern Baffin Bay, has long been known by whalers as a prime example of the "centers of sea ice removal" that occur near coasts or coastal regions bordering the pack ice. Common smaller scale coastal phenomena of this type are flaw leads of navigable size between the shore fast ice and the moving pack ice. Both the flaw leads and the large-scale zones such as North Water may be open or covered with thin ice. They may also contain fragments of thicker drift ice commonly called "clutter." These phenomena are not completely understood but are believed to be caused mainly by coastal configurations, wind, and current-induced drift.

Wind

Surface winds over the Arctic Ocean average between 8 and 10 knots. The wind regimen of Alaska is to some extent monsoonal. In summer months, a thermal low develops over the interior of Alaska; in winter months, high pressures are prevalent. Surface winds vary with locale, but generally average from 4 to 5 knots.

The frequency of gales in Alaska also vary with locale. For example, Point Barrow on the Arctic Ocean coast averages 19 gales per year, whereas Fairbanks in the interior averages only 1 gale per year.

Temperature

A variety of climatic conditions is encountered in arctic regions. Areas adjacent to one another have widely differing climatic characteristics, depending on latitude, marine influence, and topography. Annual temperature curves show three well-defined types: maritime, coastal, and continental:

1. The Arctic Ocean has a flat temperature curve during June, July, and August with small deviations from the freezing point. The winter curve is also flat, temperatures remaining nearly constant around -29°F.

2. The coastal climate is nearly similar to the maritime climate. The year consists of a long, cold winter and a short, cool summer. The annual temperature curve has the same winter characteristics as that of the Arctic Ocean, but there is a seasonal maximum in July. The mean summer temperature, however, remains below 50°F.

3. The continental climate is characterized by pronounced winter minimums and summer maximums, where the annual range of mean temperature may be as much as 110°F.

In summer, the melting of snow and ice above latitude 75°N keeps the surface temperature close to the freezing point. The number of days with a maximum temperature slightly above the freezing point is about 40 days. Near the North Pole, positive temperatures are usually observed for 10 to 15 days in late July.

Warm inland air is often transported a considerable distance over the Arctic Ocean but, in passing over the ice-filled waters, it is cooled so

effectively by contact with the ice that a sharp inversion is formed. Hence, the warm air current flows at some distance above the ground and has practically no influence on the surface temperature.

The relative humidity over ice has a maximum in midwinter (103 percent) and a minimum in June (95 percent), while the relative humidity over water has a maximum in August (96 percent) and a minimum in midwinter (73 percent). The pressure of the water vapor is small in midwinter (0.3 mb) and maximum in July and August (6 mb).

Visibility

Hoarfrost is formed when the relative humidity over ice is greater than 100 percent. The amount of hoarfrost deposition is greatest at around -20°F, while the probability of hoarfrost has a maximum at about -26°F. In July and August, there is relatively little hoarfrost since air temperatures usually are around the freezing point. Otherwise, the smallest amounts occur in April and the greatest amounts in September when the air is saturated with water from numerous open leads in the sea ice. Hoarfrost represents about 15 percent of the total annual precipitation.

Several types of fogs occur during various times of the year throughout the Arctic Basin. Water fogs form during warm months, mostly over pack ice. Steam fogs develop in winter when cold air contacts open leads in ice. Ice fogs occur when large quantities of water vapor are added to cold air. These usually are restricted to airports and inhabited areas. Radiation fogs occur in winter during temperature inversions. They are especially prevalent over the pack ice and river valleys where air movement is often sluggish.

The most serious threat of fogs is in aircraft operations, particularly since many airports are not equipped for instrument flying. Fortunately, most fogs in the Arctic are thin and shallow, and of short duration.

Visibility in the Arctic is a complex one due to the extreme clarity of the air. It is not uncommon to see dark mountains 80 miles distant. On the other hand, the lack of contrast, particularly where all surface objects are covered with new snow, results in the inability to distinguish objects close at hand. As the arctic atmosphere is fairly uncontaminated, the visibility will be reduced only, apart from fog, by precipitation or blowing snow.

Wind speeds of about 5 knots will cause unconsolidated snow to drift along the surface. At speeds of 10 to 15 knots, the snow is lifted into the air, and when it reaches a height of 6 feet the term blowing snow is used. Coastal stations around the Arctic Ocean may experience more than 100 days of blowing snow per year.

The frequent temperature inversions of the Arctic explain the many accounts of mirages. Objects that are known to be below the horizon sometimes become visible as mirages. Inversions may also interfere with the identification of landmarks through distortion, and make estimation of vertical distances more difficult.

Whiteout is a simple phenomenon with easily understood causes and only one direct effect: the loss of depth perception. This results in unexpected and sometimes disastrous consequences. The only recourse on the surface is to shuffle along at a slow pace; in the air, the only safe procedure is "instrument flying," making landing difficult, if not impossible, at many arctic airfields.

Most concern about whiteout is in relation to flying safety. Whiteout is generally a problem to the pilot in landing, taking off, and taxiing. Flying at altitudes less than 1,000 feet above the terrain, however, is particularly hazardous under these conditions.

Precipitation

Except for Greenland, precipitation is light in the Arctic. Continental areas have maximum precipitation in late summer, so a large part of the annual total falls as rain. Along the margins of the Arctic Ocean the winter accumulation of snow is, for the most part, less than 10 inches; the Siberian and Canadian arctic coasts receive as little as 5.5 inches per year (including rain and the water equivalent of snow). The annual precipitation over the Arctic Ocean is meager, about 5 inches. It is mainly in the form of snow and falls during autumn and late spring. Minimum precipitation occurs in winter.

Although the amount of precipitation along the arctic coasts is small, the ground remains saturated throughout the summer, for two reasons: (1) the ground is flat, so run-off is slight, if at all, and (2) permafrost prevents water seepage through the subsoil.

Over the central Arctic Ocean, the snow cover becomes established in late August. The thickness may be about 14 to 16 inches by late spring. Snow melting from solar radiation usually begins by the middle of June. Except in unusual years, the ice is usually snow free by the middle of July.

SECTION IV

RADIO PROPAGATION

Very low-frequency (VLF) communication systems are primarily for broadcasting over a large area with path lengths up to about 6,000 miles. These systems carry only 10 to 100 words a minute. Because of the high cost of such VLF installations, they are not used for point-to-point communications in the Arctic. Since VLF systems exist throughout the arctic region, however, they do provide a useful broadcast service as well as a means of navigation.

Arctic ionospheric conditions modify VLF propagation characteristics slightly. For most applications other than precise navigation, this effect is rather negligible.

Low-frequency (LF) systems are used for both broadcast and point-to-point communications, and also for navigation in arctic regions. The low conductivity of some of the land modifies considerably the design procedures for antenna installations as well as the overall system design. Although the low conductivity regions often present additional problems, efficient transmitting antenna systems are still feasible. LF systems have a low data rate (100 to 500 words a minute). Although the transmitting antenna installations can be large (330 to 1,300 feet high), the receiving antennas can be small (less than 3 feet high).

At low frequencies, the propagation mode involved is primarily the ground wave or a combination of ground and sky waves. The fields produced for ice cap paths are very highly attenuated compared with fields over sea water. In addition, when sky wave propagation is involved, the conductivity for a few wavelengths in the foreground of the antenna can become important. This factor must be very carefully considered in the design of any LF system in the Arctic. At present, there are installations where a relocation of several miles would increase the effective radiated power for the sky wave paths by 10 to 20 dB. Typical transmitter powers range from 10 to 50 kilowatts, with useful path lengths ranging from 150 to 1,500 miles.

Ionospheric disturbances that frequently interrupt normal high-frequency (HF) communications in the Arctic have little effect upon the low frequencies. In fact, in the lower portion of this band the field strength may actually be enhanced during such disturbed periods.

The medium-frequency (MF) portion of the frequency spectrum is of limited usefulness in the Arctic because of the rapid attenuation of the ground wave mode as well as the high attenuations on reflections from the ionosphere. The upper portion of the MF band is useful during undisturbed night conditions as well as for communications along paths that are primarily over sea water. The MF band has two advantages over VLF and LF bands: the transmitting antennas are smaller, and the atmospheric noise levels are lower. The ranges available, however, are also considerably smaller, but for some short paths, usually 60 miles or less, MF systems may be the most economical solution. There are some short-range mobile systems operating in this band. Other uses include navigation systems such as A-N beacons and LORAN.

At high frequencies (HF) it is possible to obtain good communications over long distances (up to several thousand miles) with much lower transmitter powers than at the lower frequencies. The antennas required are relatively small, about 6 to 65 feet long, and simple configurations are useful. For sea water paths, the ground wave propagation mode provides good communication for up to several hundred miles. Over poor arctic soil or ice caps, the useful range in some cases is less than 6 miles. The sky wave mode, useful in the region from 60 to 1,000 miles, makes use of ionospheric reflections from the E and F layers. In this frequency band, an appreciable amount of sky wave energy is absorbed as the rays traverse the D layer. Since this absorbing layer has to be traversed twice for each sky wave hop and the absorption for each traverse becomes quite high in polar regions, HF communication links are highly susceptible to blackouts caused by auroral and ionospheric disturbances. Since this type of attenuation decreases with increasing frequency, it is usually desirable to use as high a frequency as will effectively be reflected from the E or F layer under disturbed conditions.

The sky wave mode also suffers two additional disadvantages. First, multipath scattering, particularly that occurring during an aurora, can result in severe fading with rates roughly proportional to frequency. The rather large time delays can be so severe as to make voice signals unintelligible. Second, depending upon ionospheric conditions and the length of the path, the radio wave may penetrate the E and F layers completely instead of being reflected. This tends to limit operations to that part of the HF band below about 15 MHz.

The maximum usable frequency will depend on the time of day, the season, the terminal locations, and the phase of the sunspot cycle. Contrary to conditions at VLF, where the atmospheric noise levels are rather low, the antenna noise levels in the Arctic can be high primarily because of cosmic radio noise that has penetrated the ionosphere.

The rather simple installations required, the low radiated powers and appreciable bandwidth (typically several Hz), and the wide range of path lengths that can be employed make the HF system a fairly useful method of communication in the Arctic. The disadvantages include frequent communication failures that are due to excessive absorption, multipaths, or maximum usable frequency failure. The possible means of reducing these failures include: (1) decreasing the receiver bandwidth at the expense of the data rate, which sometimes causes frequency stability problems; (2) using vertical polarization, which would be significant, however, only for frequencies at or near 1 and 3 MHz; (3) careful selection of frequencies; (4) careful siting of antennas to permit high conductivity paths where possible for short ranges, or launching over a short section of high conductivity soil; (5) using receivers with low noise figures; and (6) SSB modulation for voice and data systems against multipath techniques.

The propagation of ionospheric scatter makes use of scattering by irregularities in the ionized D region. The effective forward scattering coefficient at very high frequencies (VHF) is quite low, and such systems require large directional antennas and powerful transmitters. For this reason, ionospheric

forward scattering is not an effective communication system for small mobile groups or ships. Its advantages include long path lengths, roughly up to about 1,000 miles, and a number of data links. Because both absorption and scatter are critically dependent upon frequency, the optimum frequency range in the Arctic is fairly narrow, somewhere between 50 and 70 MHz. Because of the rather high cost and inflexibility of such systems, their use is quite limited.

VHF propagation may also involve the scattering of radio waves from meteor trails. In this technique, transmitters operate continuously on closely spaced frequencies at each end of the circuit until a trail of meteor ionization occurs with a position and orientation that permit a predetermined energy level to be exceeded at the receiving terminal. The receipt of such a signal is used as an indication that good propagation is available, and the message is immediately transmitted at high speed until the adjoining receiver shows that the propagation mode has faded below some preset level. This intermittent communication system has the advantage of lower radiated power requirements than the standard ionospheric forward scatter system. Also, because of the character of the propagation, it is relatively private. Path lengths of up to 1,200 miles may be used. It has been found that, like the VHF ionospheric forward scatter mode, meteor burst communication links are much less affected by high-latitude ionospheric disturbances than are HF communication links.

Both types of VHF ionospheric scatter can be disturbed by major polar cap absorption caused by the widespread bombardment of the polar ionosphere by solar protons. Such events have occurred several times each year during sunspot maximums and are likely to cause severe attenuation or even complete failure of the link during daylight hours for periods of 2 to 4 days. The defect of meteor burst communication systems is the intermittence of the propagation path. The delay time depends upon the sensitivity of the system, which is a function of the operating frequency, the radiated power, the bandwidth, and the sensitivity of the receiving system. Under some circumstances, when instantaneous communication is not required, meteor burst communication is acceptable.

Another method of VHF propagation is scatter from auroral ionization. This form of scatter decreases rapidly in intensity with increasing frequency. Even so, the high frequency of 3,000 MHz has been observed. As a communication technique its disadvantages include a rapid fade rate and intermittent and unpredictable propagation. Under certain conditions in the lower portion of the VHF band (30 to 60 MHz), strong auroral scatter signals can be expected during ionospheric disturbances, and this propagation mode can then serve as an HF backup circuit.

Any such link must take into account the pronounced directional sensitivity and limited height of the auroral ionization. This ionization tends to act like a metallic mirror inclined parallel to the magnetic field lines and is most common at heights of about 60 miles. In general, east-west propagation in the Arctic would be via auroral forms to the north of the midpoint. North-south auroral scatter propagation would involve ionization several hundred miles to the north of the northernmost station. In other words, for north-south auroral

scatter modes, both antennas should be directed northward at low angles of elevation toward a common scattering column in which the line of sight is approximately perpendicular to the earth's magnetic field lines.

Ultrahigh frequencies (UHF) are useful for short-range, line-of-sight systems where the antennas are small and the powers low enough that mobile or hand-carried equipment can be employed. For conditions where the line of sight does not obtain between the transmitter and receiver, it is possible to use some type of relay mode, such as passive reflectors, mountain diffraction, airborne relays, and satellite relays. Most of these modes, with the possible exception of mountain diffraction, have wide bandwidth capabilities. At the greater ranges directional antennas are usually employed, but for moderate gains their size is not great.

Still another useful type of propagation mode in this frequency range is tropospheric scatter, which has found wide application in the Arctic. When properly engineered, such systems are reliable, are not subject to failure because of ionospheric disturbances, and may have an unusually wide bandwidth capacity (up to a few megahertz) depending upon the system parameters. The major disadvantage is the high cost of the large antennas and powerful transmitters needed to overcome the high losses of the troposcattering mode.

Although it is possible to use the superhigh frequencies (SHF) for short-range, direct, or line-of-sight communications, it is usually more economical to use VHF or UFH systems. The present-day application for SHF is in satellite relays, although some of the satellite systems are also active in the UHF region. Future use of SHF may expand, however, because it does offer the broadest bandwidth to accommodate proliferating needs. Radio circuits in the Arctic are assessed in Table I.

References

1. Sater, J. E., A. G. Ronhovde, and L. C. Van Allen. Arctic Environment and Resources. Arctic Institute of North America, November 1971.

2. Sater, J. E. The Arctic Basin (Revised Edition). Arctic Institute of North America, August 1969.

3. Landmark, B. (Ed). Arctic Communications. Advisory Group (Aerospace R&D), NATO, 1964.

TABLE I

ASSESSMENT OF RADIO CIRCUITS
IN THE ARCTIC*

Quality	Submarine Cable	VLF/LF	HF	VHF Scatter	VHF Meteor	VHF Troposcatter
Reliability	2	1	7	2	5	1
Bandwidth	2	6	4	4	4	1
Interference	1	2	4	3	2	1
Jamming suceptibility	1	6	8	3	2	1
Solar cycle effects	3	2	6	3	2	1
Initial costs	6	4	3	5	5	6
Operating costs	2	1	3	3	3	6
Totals	17	22	35	23	23	17

Legend:
Scale: 1 is excellent, most reliable, cheapest, etc.

* Source: Arctic Communications, by B. Landmark, 1964.

SECTION V

SOUND PROPAGATION

Throughout the central Arctic Ocean, sound propagation conditions are essentially uniform. This uniformity results from the stability of temperature and salinity, both with time and with geographic distribution. Most variations in temperature and salinity occur within the upper 600 meters.

Three water layers have been identified in the Arctic Ocean. The top layer is of low salinity and extends to about 200 meters. Seasonal variations in this layer result from the freezing and melting of the pack ice, but the temperature remains near 0°C. The second layer is found between 200 meters and 600 meters, and its waters originate in the Atlantic Ocean. Its temperature is above 0°C and its salinity is higher than the top layer. The third layer extends from 600 meters to the bottom. Its temperature is below 0°C, but its salinity is constant.

These three layers essentially determine the characteristics of sound velocity. The deep sound channel (SOFAR channel) exists as a half channel, with the bottom ice surface acting as the upper boundary. As a result, long-range sound propagation is possible, being disturbed chiefly by the roughness of the undersurface of the ice.

Observations of sound velocity in arctic waters are sparse. Available data indicate that the velocity profile in the Arctic Ocean is uniform and shows little variation with season. Within the top few meters the velocity is near 4,700 feet per second, although at the surface where the salinity is low and the water is warm during the summer the velocity may drop to near 4,600 feet per second. The velocity increases uniformly to 4,780 feet per second between 30 and 50 meters. Below this depth, the velocity again increases uniformly to 4,975 feet per second down to 4,000 meters. Beyond 4,000 meters, variations tend to decrease with increasing depth.

Sound propagation reaches long distances by repeatedly reflecting from the bottom surface of the ice following refraction in deeper water. This combination of conditions creates unique propagation characteristics in the Arctic. Both high and low frequencies attenuate rapidly as a result of reflection losses at high frequency and ineffective trapping in the channel at low frequencies. Best propagation occurs in the 15- to 30-Hz range. Typical time-stretching characteristics that have been noted in SOFAR ranges are present, resulting in significant pulse lengthening.

Ambient noise under the ice cover is considerably different from that found in open oceans. In discontinuous flow ice, noise levels measure 5 to 10 dB higher than in open water. Shore fast ice under rising temperatures creates conditions for the occurrence of abnormally low noise.

The character and amplitude of ambient noise are highly variable and depend on specific ice, wind, snow, and temperature conditions. For example, under decreasing air temperatures cracks form in the ice and cause impulsive noise. Both wind-blown snow striking the ice and wind effects over open water in the ice increase noise levels. Bumping ice floes in moving pack ice represent still another source of noise.

Reference

Arctic Environment Study. Final report on ARPA project No. 1314, Boeing Company, Aerospace Group, 1969. (AD 860-389)

SECTION VI

DATA COVERAGE

Coverage

Figure 5 provides a composite view of the area from which scientific data are collected. Approximately one third of the area is land, with the remainder being sea ice and water.

A survey of scientific activity in the Arctic indicated only two major U.S. funded, long-range, nondefense scientific projects which would require large-scale data collection facilities. These projects were AIDJEX and North Water. A number of investigators were interviewed and many stated that an urgent need existed for more automatic means of acquiring meteorologic and oceanographic data on a year-round basis. Presently, these data are gathered at best during 2 to 3 months of the year. At other times, data are reported by icebreakers, patrol aircraft, or submarines whose primary mission is other than scientific. Ice Island T-3 does report environmental conditions and changes daily through the Lamont-Doherty Observatory. Since the track of T-3 covers only 2 to 3 miles a day, however, the data collected represent such a small area compared to the total region that they are hardly useful for scale modeling and synoptic forecasting of environmental change.

Since 1962, the Navy Oceanographic Office has conducted ice reconnaissance flights over the Arctic Basin. Known as Project Birdseye, the aircraft, a Lockheed Super Constellation configured for ice reconnaissance (Figure 6), flies 8 to 10 missions a year, with each mission lasting about 2 weeks. Each mission consists of 10- to 12-hour daily flights over varied tracks covering the eastern, central, and western arctic regions. In addition to the various high-resolution cameras and side-looking radar, Birdseye is equipped with a laser profiler to determine the height and frequency of pressure ridges. Sensor outputs are recorded aboard the aircraft. Flights originate out of Goose Bay, Thule, and Point Barrow, and the normal mission altitude varies from 2,000 to 10,000 feet.

Another source of airborne ice reconnaissance data is the NASA Convair 990 flights. This aircraft is equipped with a variety of remote sensors (Figure 7), and it probably is the most sophisticated remote ice sensing platform in existence. It operates on a project demand basis, however, and does not provide the continuing service offered by Birdseye.

The Arctic Basin is also scanned daily by various satellites (Nimbus, Tiros, and ESSA). These satellites photograph cloud formations, terrain, and sea ice profiles via television and multispectral cameras. A swath of 600 to 1,000 miles is viewed during each scan. The sensed data are recorded on magnetic tape at NOAA and NASA ground stations. The data are then transferred to Suitland and Greenbelt, Md., where weekly ice charts and satellite photographs are produced and distributed to weather and scientific users. (See Figure 8.)

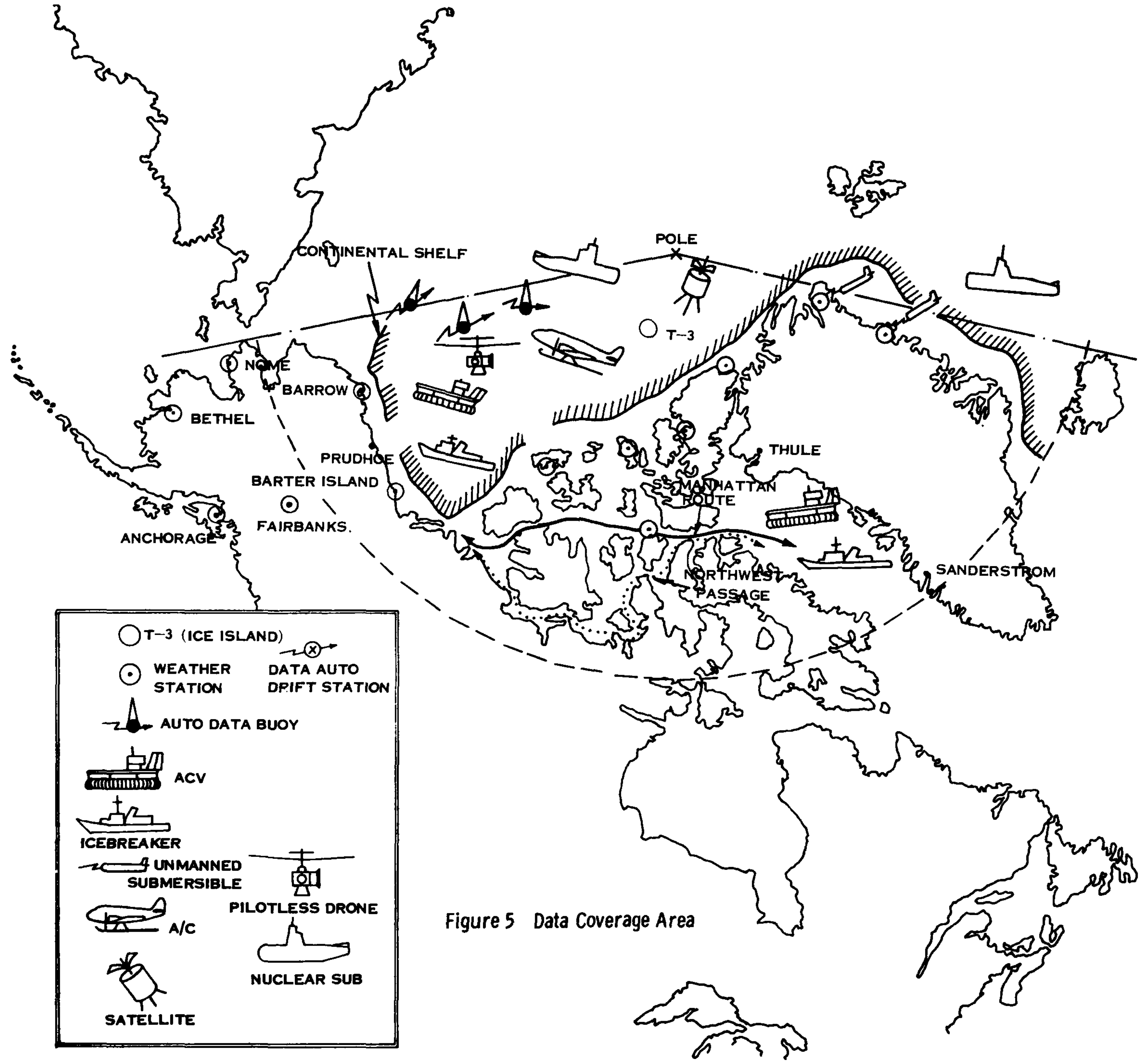


Figure 5 Data Coverage Area

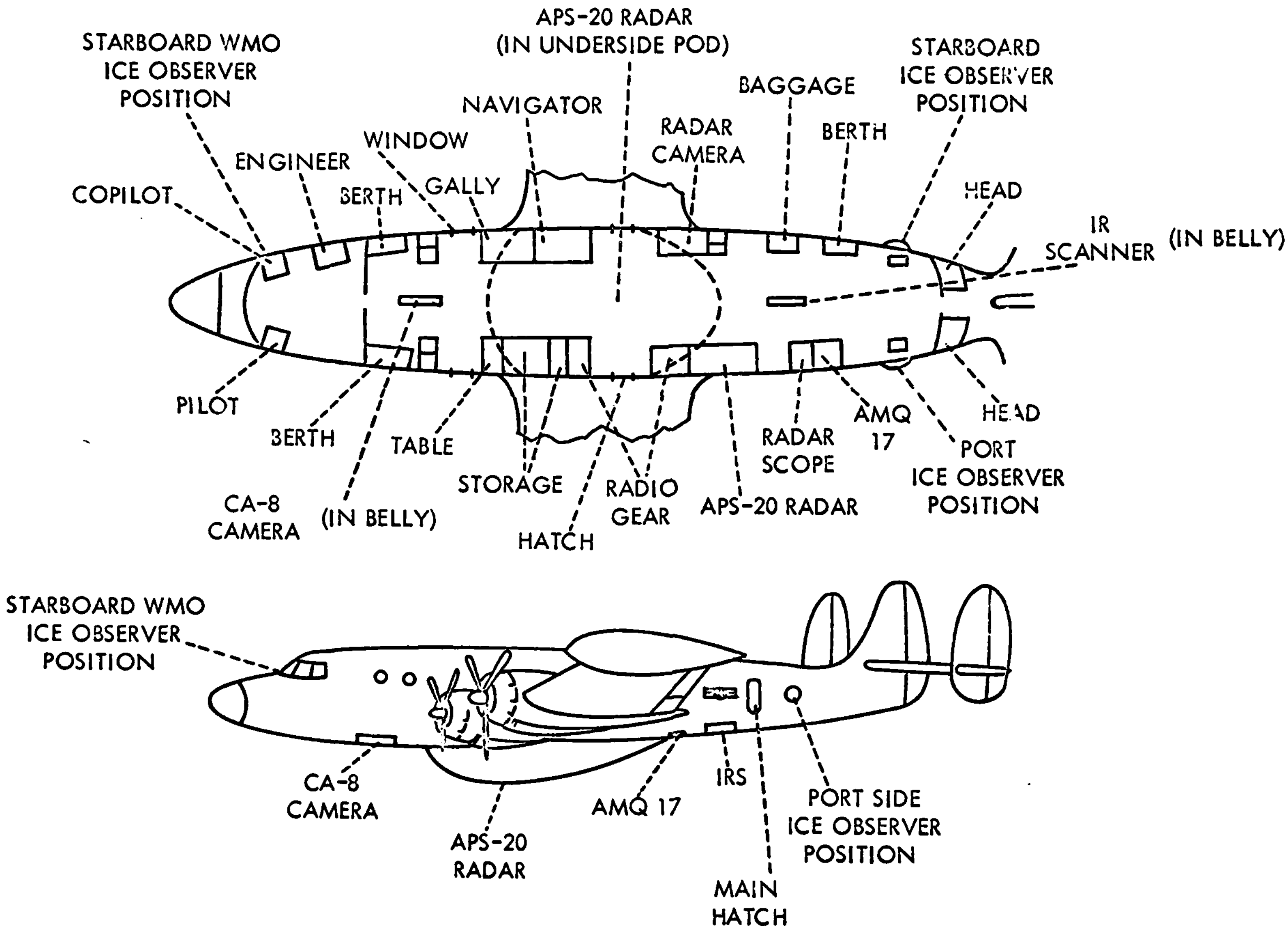


Figure 6. Birdseye Aircraft Configuration

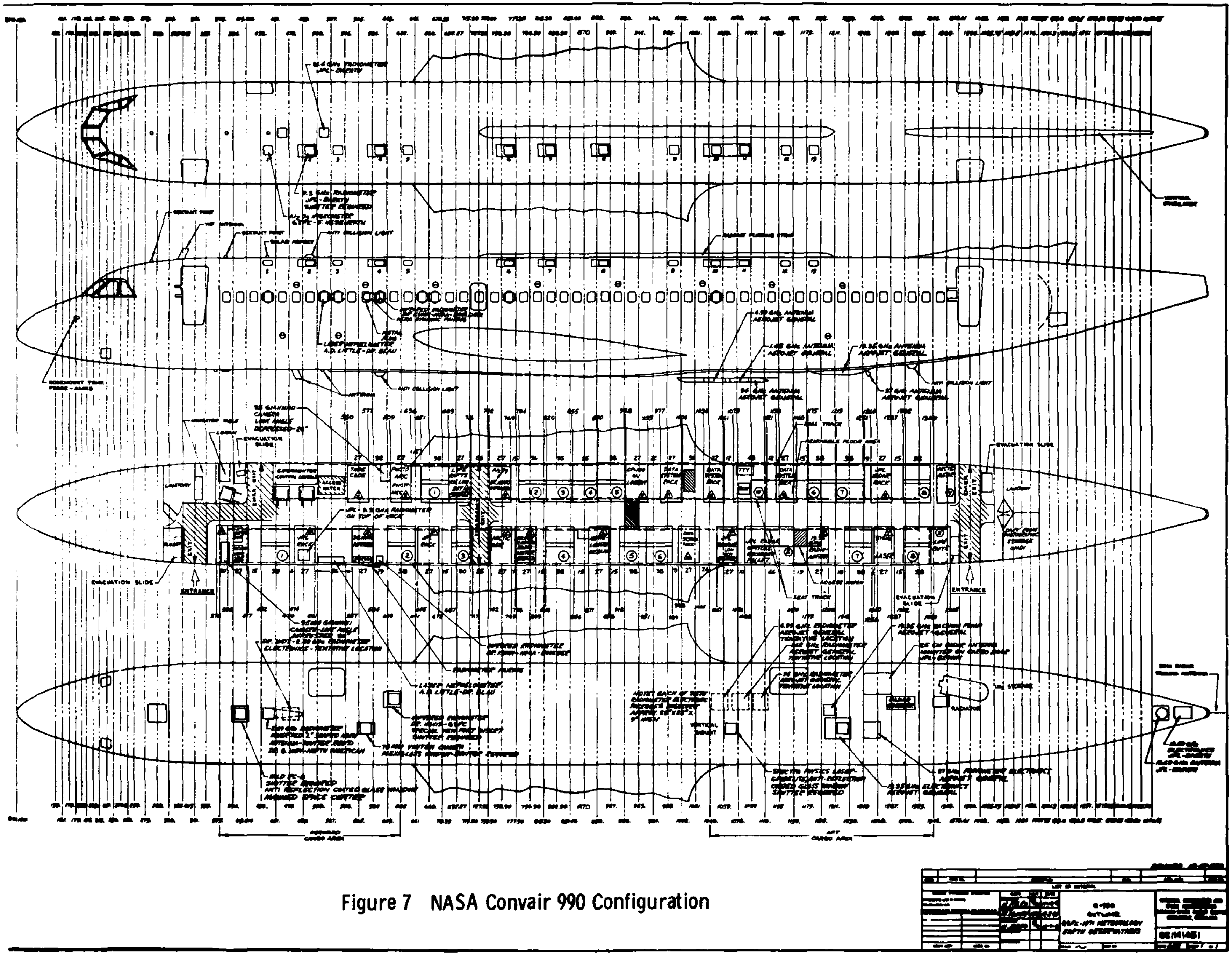


Figure 7 NASA Convair 990 Configuration

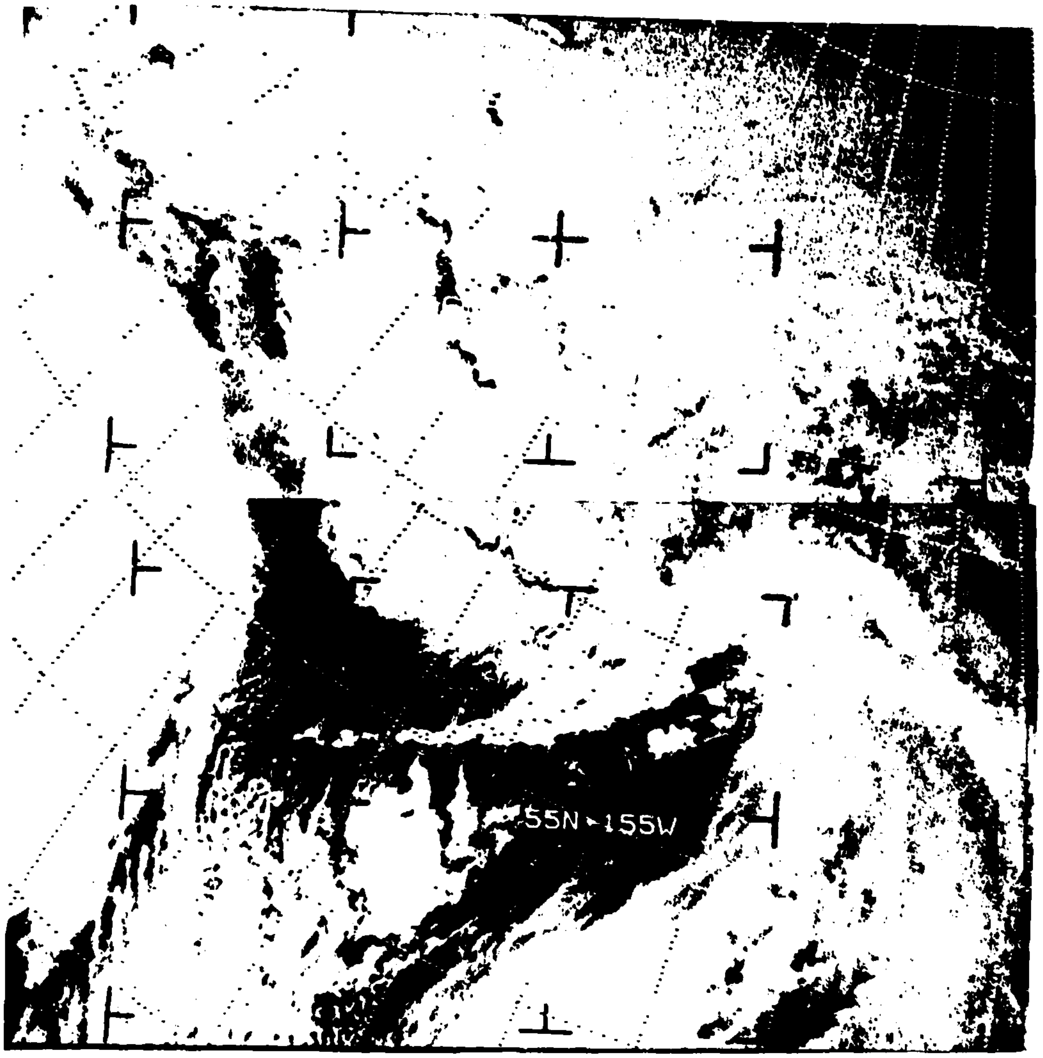


Figure 8. ESSA Satellite Photograph of Alaska

Ice observations and forecasts are also available from Danish and Canadian aircraft. Meteorologic and oceanographic information is reported from commercial ships traveling the lower arctic sea lanes as well as from U.S. Coast Guard and Canadian icebreakers plying the straits and open ocean areas. Much of these data are transferred to shore-based collection stations via radioteletype.

Upper atmospheric data are collected daily from a chain of shore-based weather stations (JAWS) operated by the U.S. and Canadian weather services. Five sites (Alert, Resolute, Isachsen, Eureka, and Mould Bay) provide meteorologic data which find their way into U.S. National Weather Service reports.

Observations of the behavior of visual aurora ionospheric measurements, polar cap absorptions, and other geomagnetic data are collected and disseminated by the U.S. Air Force (Cambridge Research Laboratory) Geopole Observatory at Thule, Greenland. Much of the sensor output information has been digital and is being recorded on magnetic tape in a format compatible with computer inputs. The information is not only available on-sight but also it is archived at AFCRL and available through NOAA's environmental data bank. No attempt will be made to duplicate the acquisition of geomagnetic or ionospheric information. Since the coverage is considered more than adequate and the data are available in magnetic tape format, any recommended system for the acquisition of this information will incorporate procedures for the efficient transfer of the tapes or data thereon to the user location.

Numerous isolated experiments are being conducted each year throughout the arctic area, some of which yield data that could contribute to an overall polar data bank derived from the acquisition systems proposed by this study. To ensure that pertinent data are accumulated from these sources in a timely and effective manner, appropriate interfaces for accessing and retrieving this information should be established within the overall data acquisition system. There appears to be no technical limitation to accomplishing proper data management. Adequate commercial and government telecommunication transmission networks exist to permit the near real-time transfer of information from remote land locations to a polar data collection center. (See Figures 9 and 10.)

Little is known of the underwater data collection systems used by the military in the arctic as such information is within the realm of national security. However, the measurement of oceanographic parameters within the continental shelf and the underwater profiling of near-shore ice ridging acoustical anomalies are typical nondefense data which should be made available to arctic scientific projects.

Platforms

Airborne and space platforms with installed sensors can perform mapping services, determine sea ice profiles, measure atmospheric parameters at high altitudes, and establish heat budget levels. These platforms, however, possess certain operational constraints which preclude all-season data collection. For example if the weather is bad, Birdseye and the NASA 990 are grounded.

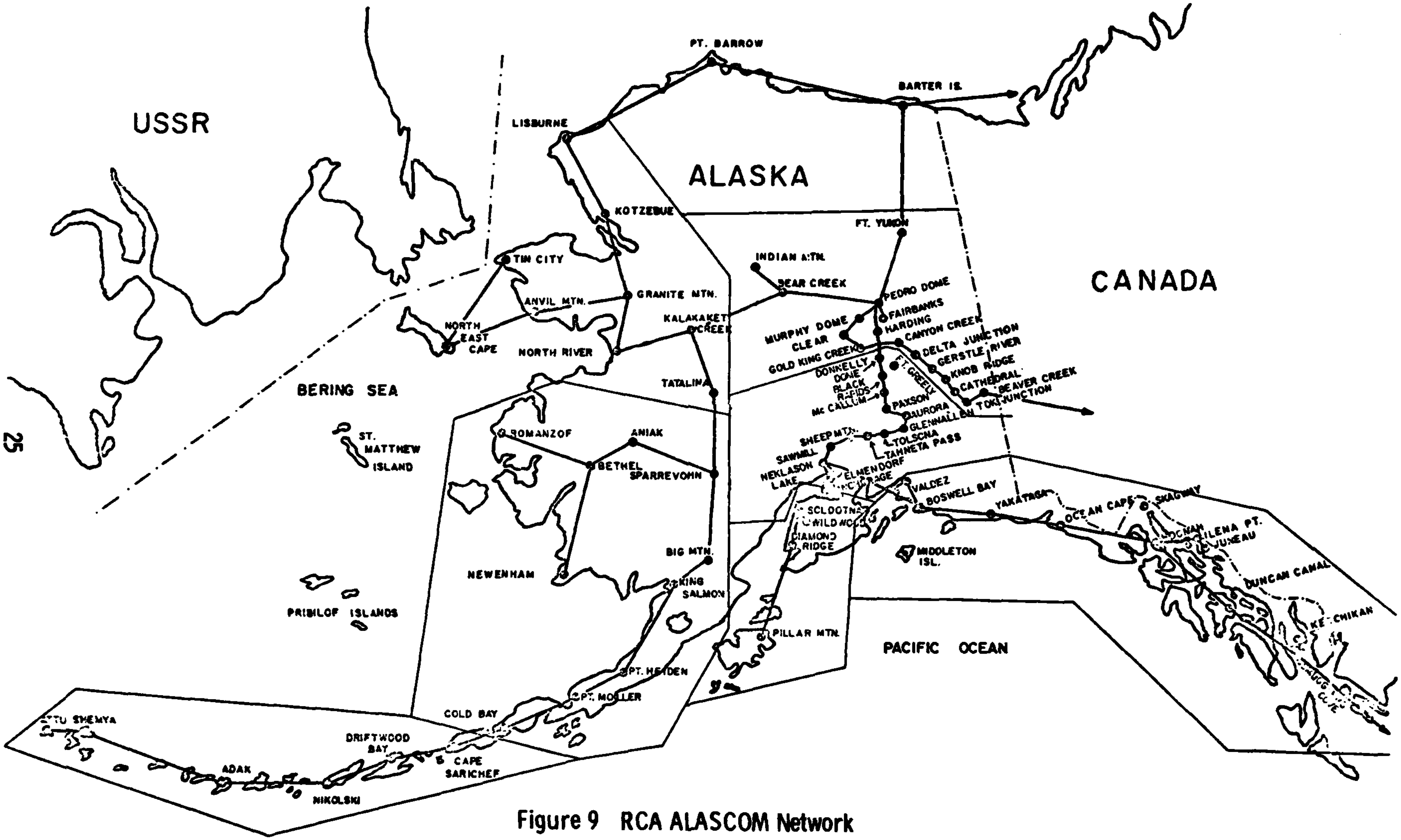


Figure 9 RCA ALASCOM Network

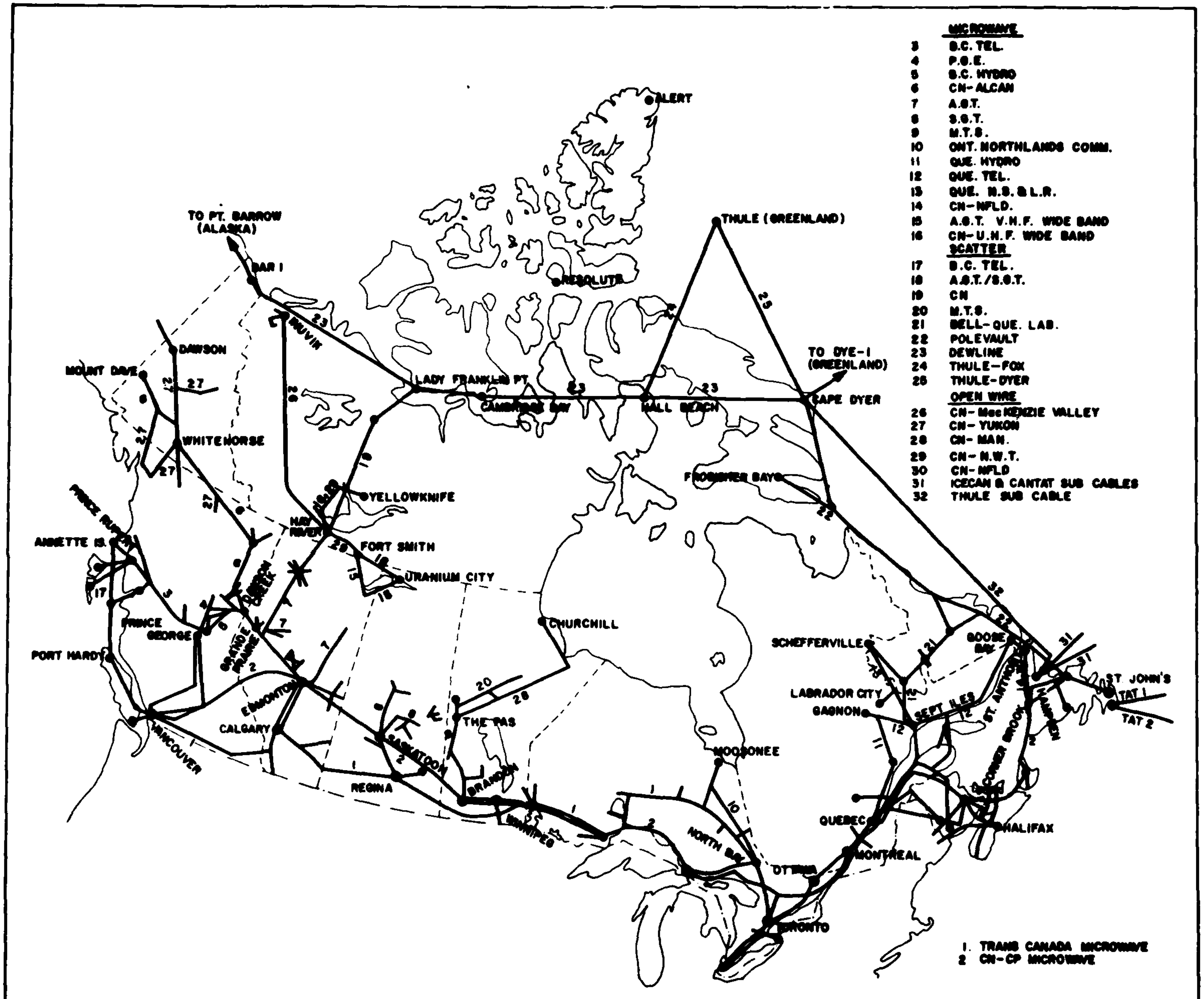


Figure 10. Canadian Communication Network

Where the sunlight is at a minimum, satellite pictures are poor. When the weather is bad or heavy cloud covers persist, ice observations are obscured or indiscernible. Also, certain parameters are measured in microscale, thus requiring sensing closer to the area of surveillance.

Because of these constraints and because of the unusual environment, this study revealed that no single platform exists that will satisfy all the sensor implantation requirements of scientists working in the Arctic. Thus, different types of platforms are needed that will suit specific areas and conditions.

For example, many locations are inaccessible for year-round research. In these cases, unattended sensing platforms appear a logical solution. Platforms which would shelter scientists during short periods of research both on the ice and underwater also seem necessary.

The results of this study indicate the following platforms could be adapted to arctic sensing and data acquisition:

1. Ice islands and multiyear floes.

2. Aircraft.

3. Drones.

4. Space satellites.

5. Research ships.

6. Submersibles (manned and unmanned).

7. Air cushion vehicles.

Ice islands and multiyear floes have been utilized frequently as manned scientific data collection platforms. Arlis stations, Ice Island T-3, and the AIDJEX main camp are typical of this application. The Soviets have launched numerous ice drift stations, identified as North Pole 1 through 20.

Multiyear floes are natural bases for remote sensing arrays in the Beaufort Sea and Arctic Ocean. Launched in accordance with recommended techniques by NAVOCEANO for proposed arctic drift stations, six to eight of these stations could be activated annually. Based on an average life expectancy of 2 to 3 years, the central Arctic Ocean could conceivably be totally instrumented for the acquisition of meteorologic and oceanographic data within 4 to 5 years. This is based on a 10 percent platform loss per year due to ice breakup or catastrophic failure of the sensor station. Within 4 years, at least 25 to 30 platforms would be actively generating scientific information from 50 miles north of the Alaskan Coast to within several hundred miles of the North Pole. Spotting multiyear ice floes poses no technical barriers. Based on previous missions, identifying 4 to 6 usable floes could be accomplished in 1 to 1-1/2 months at a cost of from $15,000 to $20,000. It is

assumed that the selected floes will enable light aircraft landings along with crews to install and service the remote station equipment. Platform maintenance is envisioned to be once every 3 months or longer, depending on the replenishment cycle of primary electric power sources.

Aircraft have been used for scientific work in the Arctic, including the C121 Lockheed Constellation (Birdseye), the NASA Convair 990, the Twin-Otter, the R4D (C47) Cessna, and various helicopters. Generally, these aircraft are used for sea ice observation missions. They can, however, be equipped as airborne data recording stations for acquiring data via telemetry. They may also be configured as radio relay links. As a short-term observation platform, the airplane is limited only by the weather and by its fuel capacity.

Drones are unmanned, remotely guided vehicles designed primarily for military missions of decoying, target marking, jamming, and electronic countermeasures. For arctic scientific applications, the drone is envisioned as a short-term surveillance platform equipped with television, radar, or photographic cameras that could be guided to questionable areas out on the pack ice. The drone could also be used to launch sonobuoys or other air droppable sensors. The fuel payload of the drone limits its range to 25 to 30 miles from its base (which could be a surface transport, an icebreaker, an air cushion vehicle, a weasel, etc.). Gyrodyne's QH-50 is a drone platform which could meet arctic requirements. The cost of the vehicle and its ground control station is around $200,000.

Space satellites are orbiting the polar regions, mapping the terrain and recording the daily changes of ice cover from approximately 500 miles above the earth. From this height, macroscale changes in ice conditions can readily be discerned when light and weather conditions permit, but higher resolution sensors are needed to detect ice flaws and leads at their earliest stages of development. A serious limitation in using space platforms is the inability to change sensors to meet other research requirements. Also, satellites are expensive, requiring investments of $20 to $25 million per launch.

Ice-strengthened research ships could serve as practical data collection platforms, particularly in Baffin Bay and navigable parts of the Arctic Ocean. Typical ships for this assignment include the retired Eastwind, the Savannah (nuclear ship), or the Apollo tracking ship. These platforms have adequate space for laboratories and housing, and can sustain missions of long duration. In addition, they are equipped with abundant primary power to handle scientific, communication, and data-processing requirements. These ships can carry a variety of support vehicles (helicopters, ACVs, weasels, etc.) for transporting personnel and equipment in support of satellite field station activities.

Manned and unmanned submersibles are indispensible for acquiring under-ice profiles, oceanographic data, and acoustic data. The manned submarine is a useful data collection platform in that it can penetrate deep areas of the Arctic Ocean inaccessible to other platforms. The submarine is maneuverable, and it can surface to observe and collect data. On-board facilities can be provided to record data in hard-copy format or on magnetic tapes. In some instances, the data can be communicated in real time to the surface for transfer

to the user. Submarines are heavily committed to military missions and are generally not available for general use. Also, the high operating costs to support a mission ($40,000 per day) would make this platform unattractive.

The University of Washington is testing an unmanned submersible platform at ice island T-3. Known as the Unmanned Arctic Research Submersible (UARS), the platform is instrumented to explore the marginal ice zone (sea ice interface), to record water temperatures and pressures at various depths, and to profile the underside of the sea ice canopy. The platform weighs about 1,000 pounds and is 10 feet long. Its designed operating depth is 1,500 feet, and it contains sufficient battery power to sustain up to 10 hours of running time (at an average speed of 3 knots). The vehicle is untethered and acoustically controlled, and is retrievable in case of power disruption or failure. Although its present range is only several miles, the homing and control system will support future operations up to 30 miles. Capital investments per platform, including tracking and control facilities, should not exceed $1 million.

Air cushion vehicles (ACV or SEV) are surface craft which ride on a cushion of air. They are amphibious and can traverse water, ice, land, or a combination of these. During the fall of 1970 an early Bell SK-5 was evaluated as a mobile experimental base on the Arctic Ocean some 75 miles north of Point Barrow. The craft participated in marginal ice zone tests conducted by the University of Washington. It was equipped with a salinity/temperature/depth probe which established sampling stations along a 15-mile test track through all types of pack ice and open water. A later version of this craft (flat deck configuration) with payloads in excess of 20 tons is available. It can be equipped with housing facilities for eight men and laboratory modules to serve as a mobile scientific workshop and data acquisition station.

Based on available performance data, this vehicle can run 10-hour daily missions and serve as a scientific field camp for missions lasting several days to a week or longer. Equipped with the proper electronics, scientific data could be collected and recorded aboard the craft or transmitted via radio or satellite relay to distant users. The ACV appears to be an excellent platform from which to conduct short-duration investigations that fall within its operational limits. The investment required to equip an ACV as a mobile data collection station varies from $1 million to $1.5 million. An attractive feature of this platform is its reported all-season operational capability which is not available in most other forms of arctic transport.

Sensors

Time did not permit an in-depth analysis of present scientific instrumentation as applicable to arctic programs. A study, performed by Texas Instruments, Inc. for the U.S. Coast Guard, assessed the status of oceanographic and meteorologic sensor developments. The study reveals that existing instrumentation will reasonably satisfy operational requirements in the Arctic for the next 4 to 5 years. Typical ranges and accuracies of meteorologic and oceanographic sensors which have application to this study are shown in Table II. There seems to be no pronounced trend that the instruments are using

TABLE II

SENSORS USED TO MEASURE
METEOROLOGIC AND OCEANOGRAPHIC VARIABLES

Variable	Instrument	Range	Accuracy
Windspeed	3-cup anemometer	0-77 m/sec	± 3 m/sec
Wind direction	Vane	0-360°	$\pm 5°$
Air temperature	Thermistor	-50° to 50°C	± 0.5°C
Air pressure	Aneroid barometer	850-1050 mb	± 1 mb
Sea water temperature	STD (platinum transducer)	-2° to 40°C	± 0.03°C
Current speed	Savonius rotor current meter	0-5.2 m/sec	± 0.05 m/sec
Current direction	Current meter vane	0-360°	$\pm 5°$
Salinity	STD	20-40 $^{o}/oo$	± 0.07 $^{o}/oo$
Sound speed	STD/SV Sing-around ceramic transducer	1400-1600 m/sec	± 0.4 m/sec
Ambient noise	Hydrophone (piezoelectric transducer)	-80 to -20 dB	± 3 dB

the latest circuit designs or components, or that they are providing digital outputs to facilitate interfacing with data-processing systems. An explanation for this appears to be the limited demand for these products.

Sea ice measurement instruments need further research and development for devices that can better classify ice features (e.g., thickness, age, concentration, and topography). Present photo-interpretive techniques, while satisfactory, are costly. Furthermore, they cannot be readily adapted for automated data acquisition and processing. Research in infrared and microwave radiometric techniques for measuring ice thickness by comparing dielectric conductivities are promising approaches and should be supported.

To achieve a year-round data acquisition, unattended and remote sensing stations are needed. The research and design progress of the RAMS platform, the Arctic Data Buoy, and the Unmanned Geophysical Observatory are indicative of the technical status and effort being expended. Each of the above arrays, however, represent the results of technical compromises or tradeoffs. For example, the RAMS platform, which is currently being field tested at the AIDJEX camp, can accommodate only minimum numbers of meteorologic and oceanographic sensors due to the limited, unattended electrical power source.

On the other hand, the Arctic Data Buoy is a low cost weather station intended to record ice surface atmospheric pressures, windspeeds, and air temperatures. The buoy is lightweight (370 to 450 pounds), can be easily deployed, and has an operating cycle of 1 year based on the mercury battery pack life. The buoy also uses the Balloon Interrogation Package electronics of the NASA Nimbus IV satellite system which provides a tailored interrogation, recording, and position location service. The Unmanned Geophysical Observatory is a land-based station for Anarctica. Its platform is designed to provide for more frequent interchange of sensors with less concern for platform survivability. The platform is designed to offer standard power supply voltages and data interfaces for each sensor. Interconnection of the sensors with the user's interface is made through an earth synchronous satellite (ATS-1) relay system which transfers the information to a data-processing center in real time.

Attempts to satisfy the worst case requirements of all users often results in a system that is overdesigned and costly. A practical approach to unmanned sensor platforms for arctic deployment is to design them with the following criteria:

- Platform survivability: 1 year with a service cycle of once every 3 months.
- Platform power: 5 watts per sensor and 300 watts per platform.
- Sensor outputs: digital.
- Data acquisition cycle: 1 to 5 minutes every 3 hours.
- Number of sensors per platform: 8 to 10.

A concept for an unmanned remote arctic sensor platform is shown in Figure 11. Called a Data Acquisition Platform (DAP), it is a duraluminum tripod structure designed for ice island or multiyear floe deployment. A floatation collar is provided to prevent the platform from being lost due to ice breakup. The collar is inflated by activation of a platform tilt mechanism. The design of the platform is modular to permit rapid assembly and disassembly of the component elements. Above-ice height of the platform structure should be 5 to 6 feet to provide for the installation of communication and beacon antennas, and a radar reflector. The tripod will contain an electronic box with the following components:

- Coder/decoder.
- Digital memory.
- Signal conditioner.
- Multiplexer.
- Synchronizer.
- Communication equipment.
- Position locator.

A detachable, sectionalized pipe (6- to 7-foot sections) will be attached to the electronic box and terminated in an underwater hydrophone sensor. This pipe will house nickel-cadimum batteries, cabling and temperature sensitive timing circuits. Current meters will be attached at various levels along the outside of the pipe. Power cables from the pipe will also connect to a thermo-electric propane or fuel cell generator located on the ice adjacent to the platform. The generator will recharge batteries and serve as an emergency power source during battery failure.

Precise location of the DAP that is being constantly moved by the ice is required by the data collection system. Existing positioning systems and their chief characteristics are presented in Table III. Three of these systems are operating worldwide and offer beyond line-of-sight operation (which is the operational mode of the DAP). These include Omega, with signal rebroadcast capability, and Transit and IRLS satellites. From the accuracies cited in Table III and the long-term availability of this service, selection of the most favorable platform location system favors the Navy's Transit approach. Low-cost terminal equipment, space, weight, and power drain are now available for adaptation to the DAP (e.g., the Satellite Positioning Corporation SCS-100).

The weight of a DAP is estimated at less than 1,000 pounds. The platform and its components can be packaged to fit a C-47, a helicopter, an ACV, or an icebreaker. Reassembly and operational checkout of the unmanned station should take 1 day utilizing two qualified technicians. The DAP maintenance cycle (including power source replacement) is planned for once every 3 months. Except

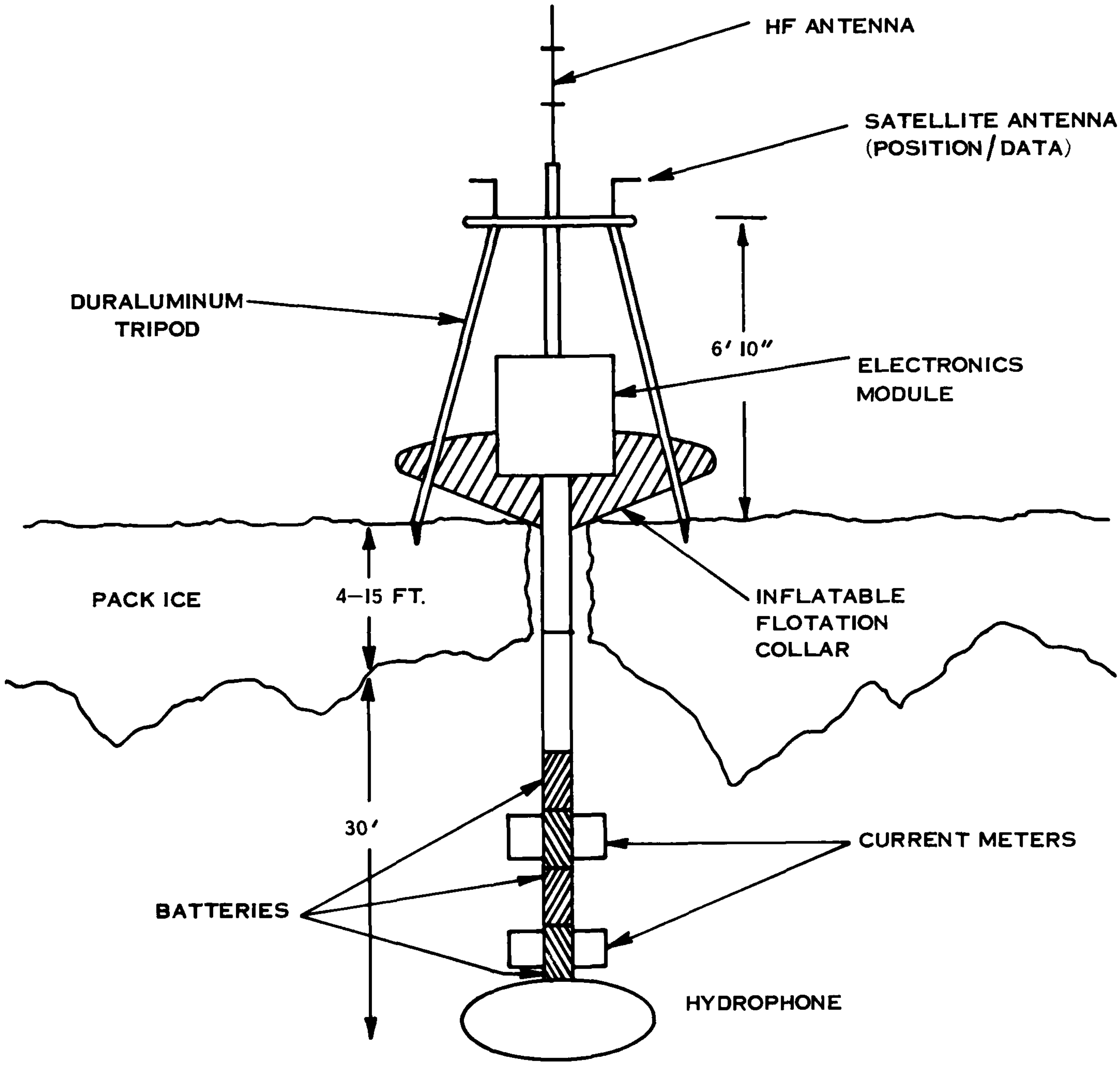


Figure 11 Data Acquisition Platform (DAP)

TABLE III

CHARACTERISTICS OF AVAILABLE POSITIONING SYSTEMS

System	Range	Accuracy	Frequency
Omega	3000-6000 nm	±1.5 nm	10-14 kHz
Loran A	700-900 nm	1-5 nm	1600-2500 kHz
Loran B	300 nm	45-300 ft.	1900 kHz
Loran C	1200 nm	50-1200 ft.	90-110 kHz
Lorac A	200 nm	15-400 ft.	1600-2500 kHz
Lorac B	300 nm	15-400 ft.	1600-2500 kHz
Decca Hi-Fix	20-150 nm	2.5-10 ft.	2 MHz
Raydist-DM	200 nm	12-100 ft.	16-50 MHz
Shoran	25-75 nm	25-100 ft.	230-310 MHz
Autotape	100 km	50 cm±10ppm	2900-3100 MHz
Transit (satellite)	WW	5m±0.1 nm	150-400 MHz
IRLS (Nimbus satellite)	200 km	±2 km	465 MHz
Tellurometer	10-30 nm	0.15-0.5 ft.	3000 MHz

for sensor and emergency power source costs, a DAP station is estimated to cost $12,000 to $15,000 a copy in lots of 50 to 100 units.

References

1. Wittmann, W. I., C. W. Senior, and L. F. Stiles. Proposed Arctic Drift Ship Station Study. Navy Hydrographic Office, Reprint June 1965.

2. U.S. Coast Guard Oceanographic Sensor Study. Contract DOT-CG-90505-A, Texas Instrument, Inc., May 1970.
Vol. I - Tutorial discussion
Vol. II - State of art of oceanographic and meterological sensors
Vol. IV - Formating and transmission of data
Vol. V - Analysis of applying standardization techniques.

3. AIDJEX Bulletins No. 1 through 10. Arctic Ice Dynamics Joint Experiment, Div. of Marine Resources, University of Washington.

4. Development Program--Remote Auto-multipurpose Station (RAMS). General Motors, Delco Electronics.

5. U.S. Coast Guard Air Cushion Vehicle Evaluation. San Francisco/Point Barrow, January-August 1971.

6. Operations of the National Weather Service. NOAA, U.S. Department of Commerce, October 1970.

7. Hastings, A. D. Jr. Arctic Basin--Locations of Climatic Stations. U.S. Army Engineer Topographic Labs Report ETL-TR-71-5, Dec. 1971.

8. Francois, R. and W. Nodland. Unmanned Arctic Research Submersible System Development Report. Phase I, Appendix A, Report of Arctic Technology Development at the University of Washington, June 70-June 71.

9. Experimental Arctic Data Buoy (interim report). APL, University of Washington, Feb. 1972.

10. Feasibility Study of an Automated, Unmanned Geophysical Observatory for Operation in Antarctica. Stanford Electronics Laboratory, Feb. 1968.

11. Church, J. and R. Pierce. An Expendable Remote Operating Weather Station (Erows). Air Force Cambridge Research Labs, Bedford, Mass., Aug. 1971.

SECTION VII

DATA ACQUISITION SYSTEMS
(LONG-TERM AND SHORT-TERM NETWORKS)

Data acquisition system concepts are classified by the time constraints imposed in acquiring the data and then transmitting the data to the user. Long-term systems comprise networks where data may be gathered on a continuing basis through permanent or semipermanent facilities, and then transmitted in real time or near real time to a data collection center where the data are conditioned for use by scientists or stored for subsequent retrieval by other users.

Short-term data collection systems consist of integrated data-gathering facilities configured for missions where the data are available only for limited periods (several hours to several days) and confined to a specific locale.

Further the concepts proposed here are predicated upon the following premises:

1. Implementation of any of the recommended systems will be technically feasible by 1975.

2. Sufficient numbers of ice islands or multiyear floes can be located in the Beaufort Sea/Arctic Ocean on which can be established unmanned sensing stations with a life cycle of 1 year or longer.

3. Long-term data acquisition systems will provide year-round operational capability.

4. External accurate position location systems (e.g., Transit, IRLS, or equivalent) will continue to service the arctic area, or new facilities will be available to establish fixes within 1 mile.

5. Research and development of air cushion vehicles and unmanned submersibles will provide operational platforms for arctic deployment.

6. No political or legal barriers exist to preclude the launching of sea ice mapping and/or scientific observation satellites.

7. Representative scientific data of the Beaufort Sea/Arctic Ocean sea ice characteristics can be obtained south of the 78th parallel (500 to 700 miles north of the Alaskan coastline).

8. The communication system will carry analog, digital, teletype, standard voice, and low-speed facsimile transmissions. High-resolution spectral and television photographs, and radar maps

will be recorded on-sight and transported to the polar data center for reduction, analysis, rerecording, and storage in the data bank.

9. Typical daily traffic characteristics to be communicated by the long-term network include:

   a. Scientific projects where the data rate is 500 to 1,200 bits per second; where transmission occurs for 5 minutes once every 3 hours; and where the volume is about $2x10^6$ bits per day.

   b. Automatic remote sensors where the digital volume is about $5x10^5$ bits per day, based on eight selective pollings per day.

10. Mooring (topside) of data buoys and platforms off the east coast of Greenland is not feasible.

11. The outer limit of the geostationary satellite coverage zone does not extend north of 70°N, thus making the satellite unsuitable as an arctic communication relay.

The functional structure of these long-term data acquisition systems to be described is illustrated in Figure 12.

Long-term Networks

Satellite Relays

Three types of unmanned polar-orbiting satellites have application to arctic data collection requirements. They are:

. Data communication relays.

. Polar-to-synchronous satellite data relays.

. Ice observation and data relays.

The available and planned NASA satellites listed in Table IV meet the general system requirements of the above types. In the data relay mode, the satellite is the tie line between sensor inputs and the collection facility. Inputs are acquired from DAPs, RAMS/LAMS, arctic buoy stations, and manned data platforms (ships, ACVs, aircraft, etc.). This information is released to the satellite by preprogrammed commands from the satellite control facility (normally NASA Goddard) on a platform polling basis. Depending upon the launch characteristics, the orbital pattern, and the inclination of the spacecraft, visibility periods for data acquisition vary from 20 minutes to as long as 8 to 12 hours per orbit in the case of the circular polar and critically inclined (63.5°) satellite systems. As the visibility per orbit increases, however, so does the distance of the satellite from earth, which imposes higher signal detection capabilities on the ground receivers.

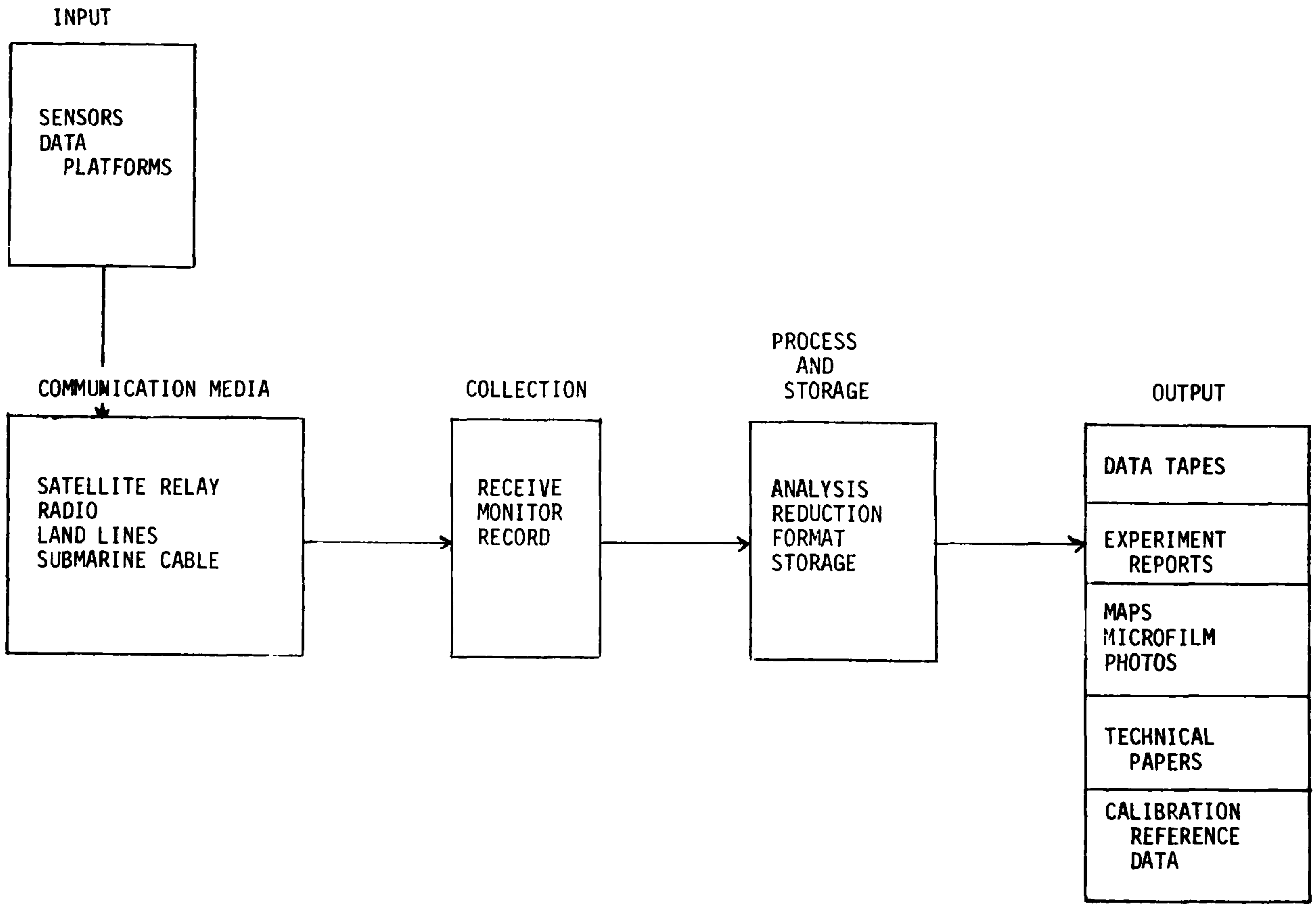


Figure 12. Functional Diagram of Data Acquisition System

TABLE IV

NASA SATELLITE SYSTEMS

Spacecraft	Orbit		Polar Visibility (Minimum)	Data Channels	BW* (kHz)	Position Location	Telemetry Frequency (MHz)	Launch Status
	Type	Period (Minutes)						
Nimbus 4	Polar	108	20%	Yes	30	Yes	400/466	In orbit
Nimbus F	Polar	108	20%	Yes	30	Yes	400	1974-75
Tiros N	Polar	114	25%	Yes	35	Yes	400	1975-76
ERTS A/B	Polar	103	20%	Yes	100	No	400	1972-73
ATS F/G	Synch.	1,440	None	Yes	**	Yes***	400/465	1975-76

* Data Communication Channel.

** Nimbus relay: 40,000/12,000.

*** Place system for aircraft only.

For the polar orbiting systems identified in Table IV, the visibility window over the North Pole region is close to 20 minutes for each pass. During this time, from 30 to 40 platforms can be interrogated and digital traffic up to 20 kilobits per second can be processed through the relay during a single pass. By additional commands, the information can be transferred to ground receiving stations in near real time as the spacecraft approaches the reception zone of a ground collection complex. Suitable ground receiving stations include the NASA STADAN site which controls and collects data from Nimbus satellites and the planned ERTS spacecrafts, and the NOAA operation which receives weather data acquired by ESSA and Tiros satellites. The ESSA satellite, however, is not equipped with separate data channels that can be used for communication relaying.

At the earth terminal the data are recorded on magnetic tape. Facilities are available on-site to monitor the data for quality and proper transmission. Via common carrier circuits, the tapes are retransmitted to NASAs Information Processing Facility (Goddard) where proper timing information, positioning, and other engineering factors are applied to the inputs. Local computers further program the data for inputting to a central processor where scientific modeling or hardcopy readout can be prepared for investigators or other users. NASA indicates a 2-week turn-around cycle from data acquisition to processed readouts.

In the proposed system, the taped outputs collected at the NASA satellite ground stations should be relayed by common carrier circuits to a Polar Data Center in central Alaska where monitoring, quality control, preprocessing, and analysis can be performed, thus shortening the long turn-around processing cycle by NASA. At the Polar Data Center, data banks, for both temporary and permanent storage, will be established where arctic statistics and other scientific information can be amassed, stored, and accessed by users.

The transfer of large quantities of data from a polar orbiting satellite to the ground collection station can be eased by relaying in space to a synchronous satellite (e.g., the ATS F/G which is scheduled for operation in 1975), which can establish a fixed communication path to NASAs earth station. The concept is shown in Figure 13. An additional benefit from this configuration is that the ATS F/G satellite can establish more precise orbital parameters of the polar satellite.

The advantages of satellite relay systems are:

1. Continuous operation on a year-round basis which is unaffected by electromagnetic disturbances.

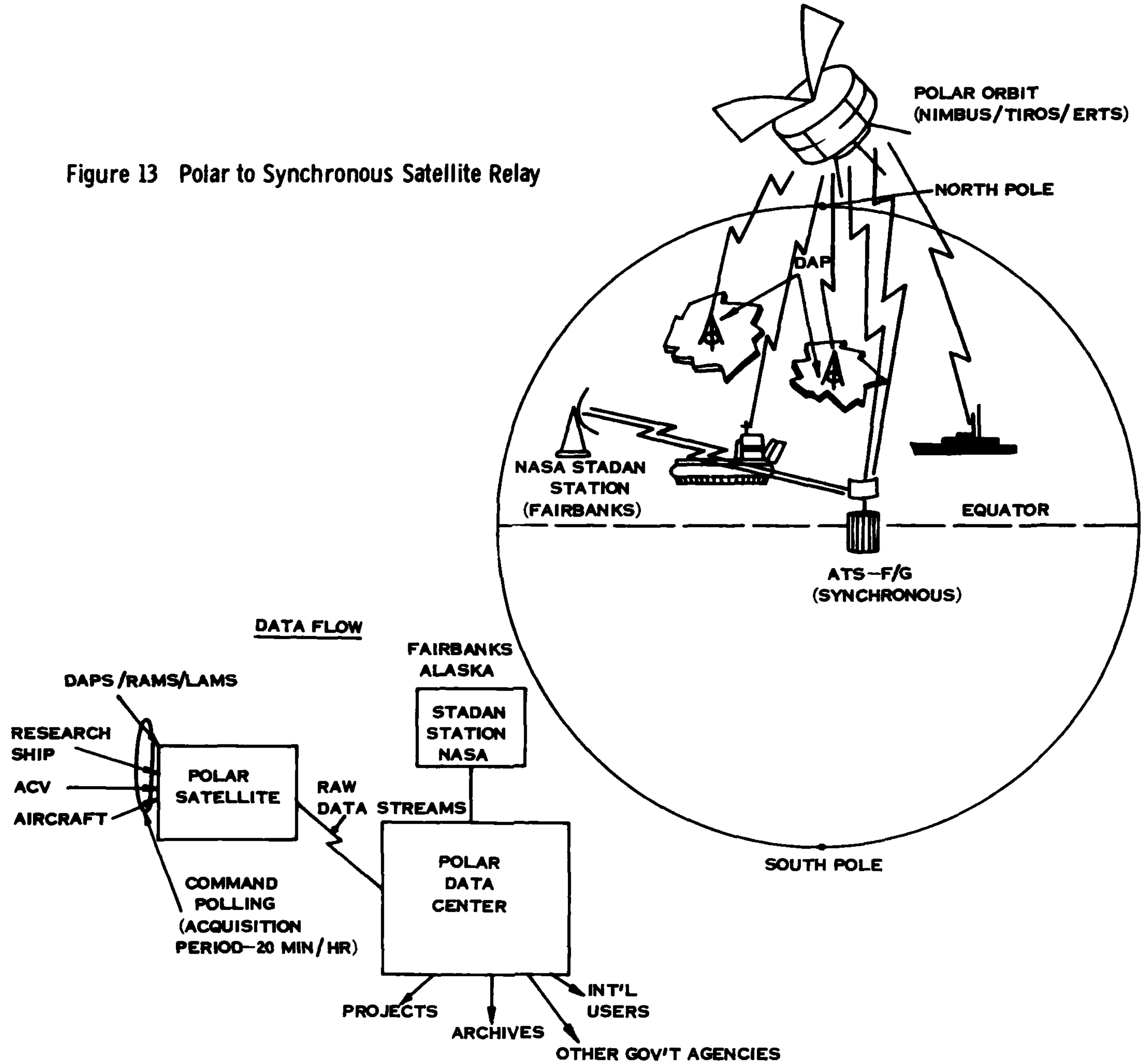
2. Minimum logistic support.

3. Existing systems with medium bandwidth data-handling capabilities are systems with proven hardware.

4. System can acquire scientific data from the South Pole as well.

5. Present operational systems (e.g., Nimbus) provide macroscale ice reconnaissance data which would be useful inputs to the data bank.

Figure 13 Polar to Synchronous Satellite Relay



6. Existing systems could be used as a test bed to develop specifications for highly improved polar-oriented systems. During the interim, the existing system (Nimbus) could be assigned for DoD use at no charge, or possibly at an annual rate of $500,000 for an extended period.

Limited visibility periods for data collection, as compared to synchronous satellites, and high initial capital investment for a new system are the principal drawbacks to polar satellite relay data acquisition.

An estimate of the funding required to implement a new polar-orbiting satellite data relay system is around $20 million. This figure includes the cost of the spacecraft, launch vehicles, tracking and ground facilities, and installation. Annual operating and maintenance expenses over a 5-year life expectancy should not exceed $5 million. The amortized fixed and operating costs of this system could average $9 or $10 million a year.

A more useful satellite system would be one that incorporated an array of on-board sensors which could record high-resolution, macroscale ice images and profiles as well as radiometric devices which could measure heat change and distribution. These data would be synchronized with information acquired from on-ice, unmanned sensor stations (floes) and forwarded to the polar data center via an earth receiving station. Present high-resolution imaging instruments do not meet arctic requirements. Furthermore, the power required to operate these devices exceed the on-board power supply of the satellite. Within the next 5 years, these hurdles should be overcome, paving the way for a combined ice observation and data relay satellite system which could better satisfy collection needs.

HF Radio Relay

This is a narrowband network capable of handling data rates up to 1,200 bits per second for ranges up to 1,000 miles. (See Figure 14 and Table V.) A chain of medium-powered transmit/receive terminals are positioned along the Arctic Ocean shoreline from which unmanned sensor platforms on drifting floes are interrogated periodically (each station transmits for 1 to 2 minutes during a 3-hour polling cycle). On command from the shore terminal, the sensor outputs are broadcast to the nearest shore receiving site and forwarded in real time to the polar data center, which is interconnected with other shore receiving sites via existing military or common carrier trunk circuits (e.g., White Alice, Dewline, BMEWS, and Canadian telecommunication links). Other operating platforms, both manned and unmanned, may enter the network at any point within communication range during unprogrammed polling periods. The terminal reception zone is within the range of most scientific field work (600 to 650 miles out on the Arctic Ocean) and should be within reach of most unmanned drift stations.

The prime advantage of this system is the availability of hardware and interconnecting telecommunication links. The system does have drawbacks, however. Its bandwidth is capacity limited, and it is frequently blacked out by auroras and polar cap absorptions. Unlike the polar satellite relay, this system does not offer any self-contained position location service, which means that unattended platform fixes and tracks must be predetermined.

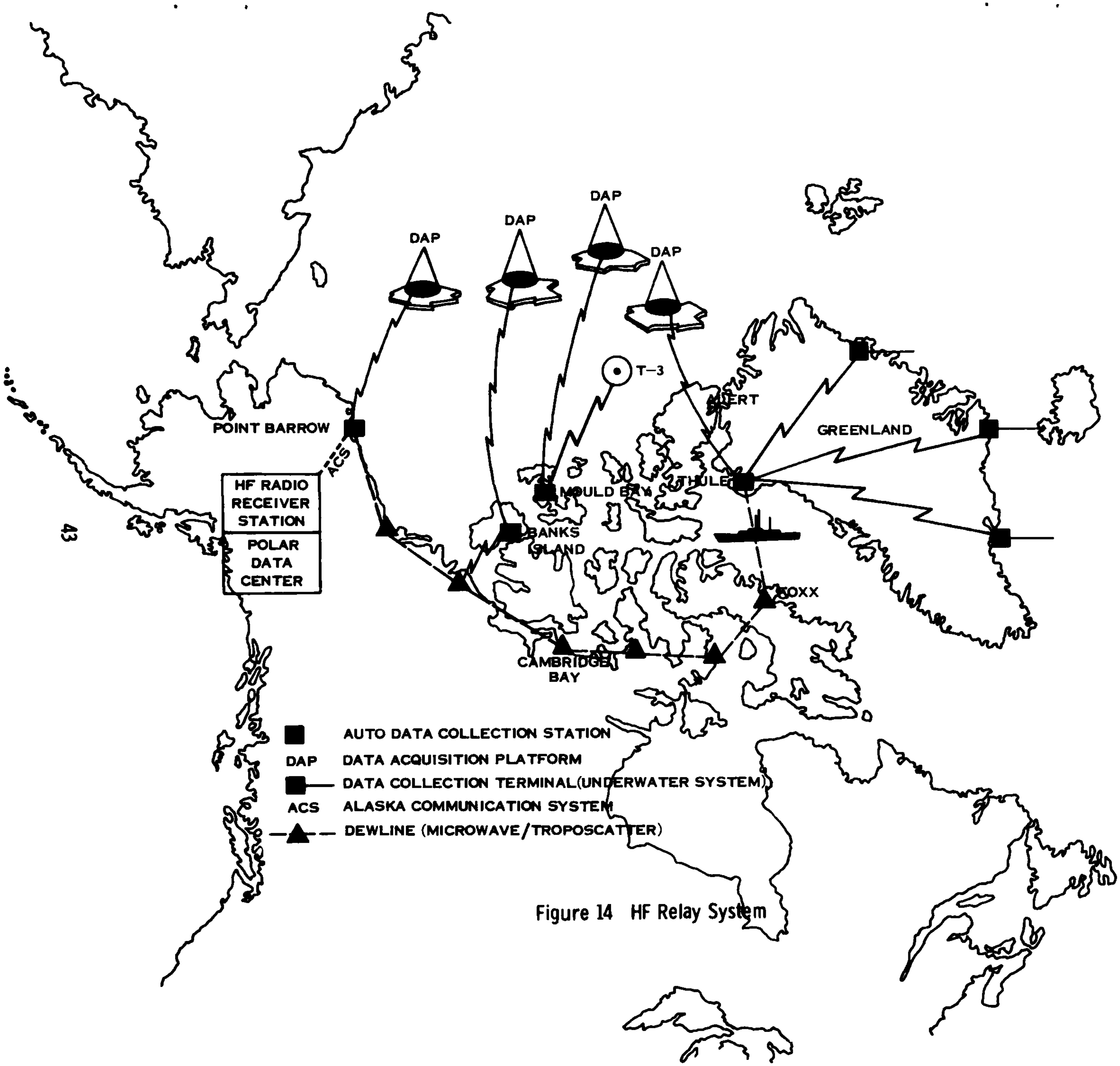


Figure 14 HF Relay System

TABLE V

HF RADIO SYSTEM TERMINAL CHARACTERISTICS

Transmitter			Range (Miles)	Antenna System	Number of Channels (Voice)	Bit Rate (BPS)
Power (Watts)	Frequency Range (MHz)	Modulation				
20	5-30	FM	360	Dipole	1 (3 kc)	1,200
150	5-30	SSB-AM	400	Directional (V)	1 (3 kc)	1,200
250	5-30	SSB-AM	500	Directional (V)	1 (3 kc)	1,200
500	5-30	SSB-AM	700	Directional (V)	1 (3 kc)	1,200
1,000	5-30	SSB-AM	700-1,500	Log periodic or diversity	1 (3 kc)	1,200
5,000-10,000	5-30	SSB-AM	Over 2,000	Rhombic or log periodic	1 (3 kc)	1,200-2,400

Each HF shore terminal could also serve as topside interface and relay station for an underwater data collection system (described later in this section). Also, macroscale sea ice mapping could be obtained through Birdseye flights, with the recorded film outputs being delivered to the polar data center for further reduction and insertion into the data bank.

A minimum system investment (equipment and installation) of $1.5 to $2 million is foreseen. Annual expenses for operation and maintenance should be $500,000.

Drifting Arctic Research Laboratory

The hub of this data collection system is an ice-strengthened ship which would be launched into a drift track (Figure 15). As a mobile base, the ship offers ample space, shelter, and complete logistic services to support long-term scientific investigations. It can provide long-distance communication links, and it can be equipped with recording and data-processing facilities to handle the production of final usable data outputs. Possible candidates for mobile platforms are Apollo tracking ships and retired icebreakers (e.g., the Eastwind).

While pressure ridges and ice lockup constitute the major risk to the safety of these vehicles, there appears no reason why these hazards cannot be avoided with improved navigation aids and skilled piloting. Ship assignments could be planned to take advantage of periods of low ridge concentrations and high open water areas. Through its own power, the ship should be capable of maneuvering out of any serious ice lockups.

Based on previous arctic drift ship station studies, the platform could cover 600 to 700 miles in one season. It could return to port two or three times per year for mission reassignments, repairs, resupply, and crew leaves.

The advantage of this system is that a costly long-distance communication network is not needed between sensor pickup sites and the data collection processing center. Too, with on-sight analysis by scientists, data preparation time is reduced and data management is made easier.

Time did not permit an analysis of costs, but consultations with ship experts and a review of several proposals on this subject indicate that an investment of $8 to $10 million for hull ice strengthening is reasonable. Modifications to convert the ship to a mobile laboratory would require another $1.5 to $2 million. Based on quoted rates of $3,000 per day for commercial ship leases, annual operational costs should be budgeted at not less than $1 million.

Underwater Data Collection System

The difficulties of communicating for any great distances or depths in water are well known. Further, the immediate needs and interests of arctic scientists are concentrated in observations of environmental changes along the continental shelf and in the marginal ice zones. A configuration of instrumentation and communication facilities to meet this need is illustrated in Figure 16.

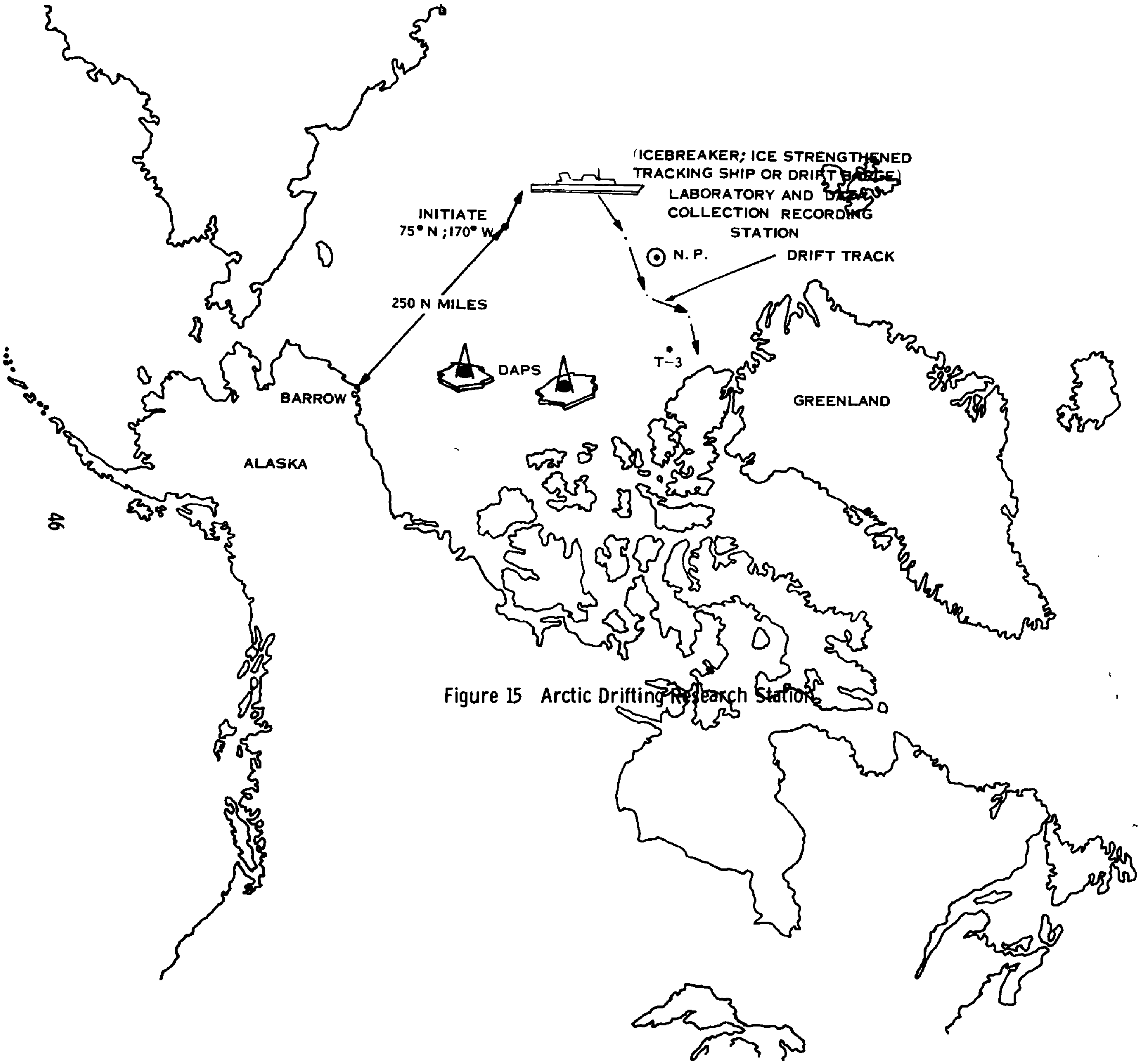


Figure 15 Arctic Drifting Research Station

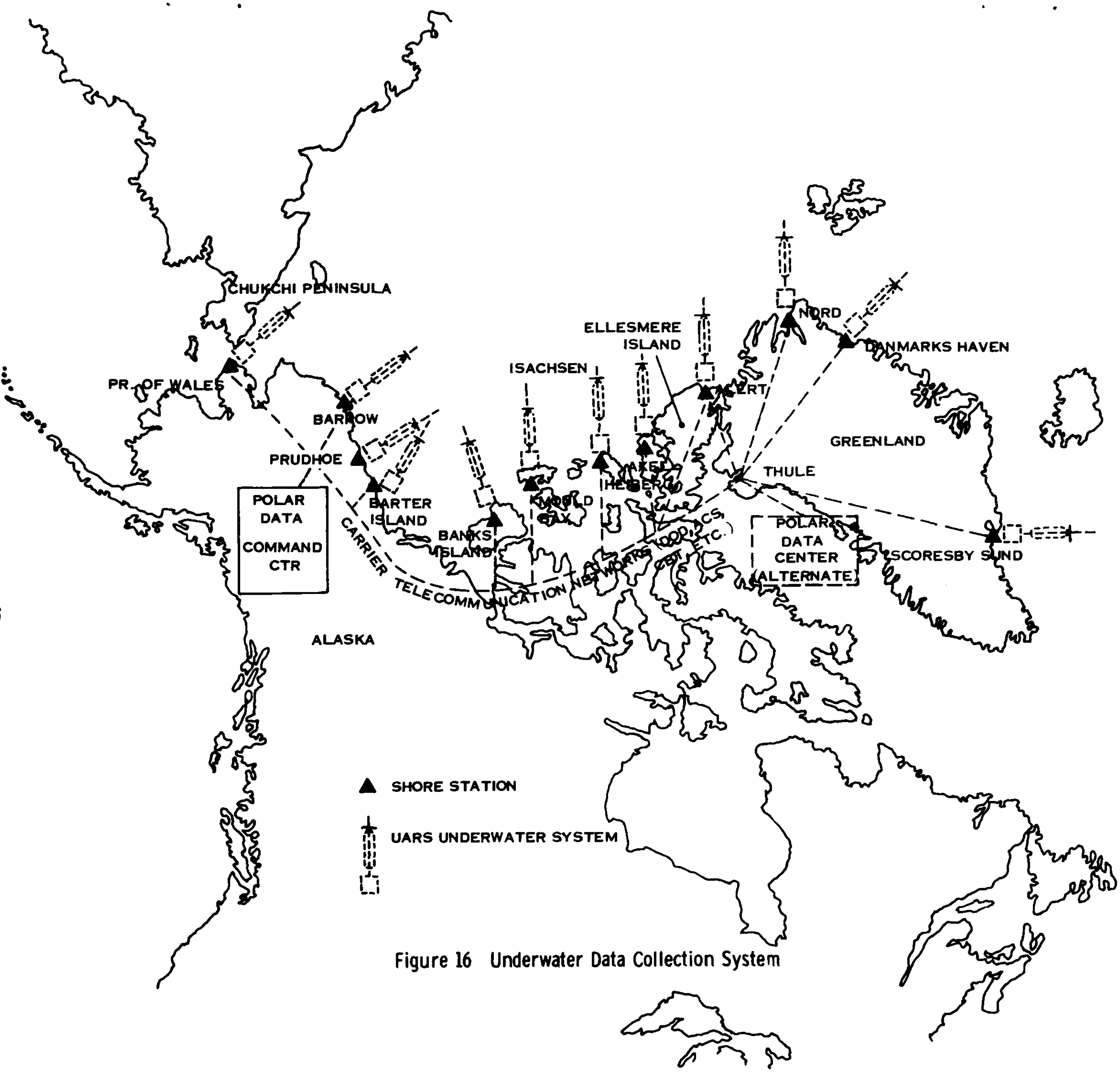


Figure 16 Underwater Data Collection System

The input sensors of this data-gathering network are contained in the unmanned UARS submersibles. Guided by an acoustic beacon system implanted on the coastal shelf bottom near the shore, these submersibles will follow programmed tracks along radials extending 25 to 40 miles off-shore. Each submersible is equipped to gather under-ice profiles and salinity/temperature/depth data. The data are recorded on-board on magnetic tape. At the completion of a run, which would be automatically controlled from a shore station via cable connections to the underwater beacon mooring station, the submersible would transfer the data via cable link into a temporary data storage bank at the shore station. There the signals would be amplified and telemetered to the polar data center for further analysis, calibration, reduction, and permanent storage. The shore station locations (shown in Figure 16) were selected to facilitate interconnection to existing common carrier and military trunking networks.

In addition to telemetry equipment and guidance and control electronics aboard the UARS, auxiliary power units will maintain a trickle charge on UARS batteries through a cable connection at the underwater homing site. An on-board hydrophone will enable the UARS to detect moving objects at each installation. Also, each UARS station operates on commands preprogrammed by a central command post at the polar data center.

Costs for implementing a minimum network of five stations along the northern Alaska coast are $7.5 million for UARS stations and shore telemetry and $1.5 million for the data center and command and control site.

Short-term Data Collection Systems

Air-dropped Sensors

This technique has been demonstrated in other geographical regions. Since World War II, the U.S. Navy has utilized sonobuoys to sense and track underwater motion and events. Sounds of submarine propellers and water temperature are detected and relayed via radio to a deployment vehicle, generally an airplane or a helicopter. Recently, the U.S. Coast Guard introduced an air-ice penetrometer which can be air dropped from altitudes of 5,000 to 8,000 feet. Impacting ice at 550 feet per second, the projectile can penetrate up to 12 feet of ice. As it strikes the ice, it pulls apart. The tail section containing a radio antenna protrudes above the surface, while the forward section containing a telemetry package cuts through the ice to the water below, releasing an electric cable as it goes to retain contact with the section and the radio antenna. An accelerometer in the telemetry package senses the deceleration of the projectile as it penetrates the ice and relays this information to an airborne platform where it is recorded. A ground-based computer then converts the information into ice thickness measurements.

The U.S. Air Force Cambridge Research Labs are developing an expendable remote weather station dubbed EROWS. Deployed by light aircraft into generally inaccessible areas, the sensor package records and broadcasts, on command, air temperature, barometric pressure, windspeed and direction, precipitation, and cloud cover for up to 10 days. The delivery system is a free-falling projectile, and batteries operate the sensors, radio, and recorder. The sensors and the

telemetry/electronics are contained in a package 14 inches long by 6 inches in diameter. A master control station aboard the airplane commands up to 10 EROWS stations to transmit outputs. The digitized outputs are tape recorded aboard the aircraft.

Mating an EROWS package with an ice penetrometer appears feasible. Sensor arrays comprised of sonobuoys, ice penetrometers, and EROWS would be useful for rapid assessment of local environments.

A projectile profile for short-term arctic surveillance missions is depicted in Figure 17.

Integrated Mobile Data Collection Platform

Occasions arise when short-term data collection activities cannot be conducted by remote control. Then the scientist becomes important in the acquisition cycle. If the time involved extends to several days or weeks, then the problem posed is how to respond to the requirement. If time is urgent and if the distance to the target area is reasonable, the standard solution is to airlift men and supplies to the area as long as the weather is suitable. More often than not, however, flying weather in the Arctic is poor, and the mission must be scrubbed or delayed. Also to maintain men on the sea ice for any length of time requires advanced planning of all logistics support. Finally, there are times when it would not be safe to set up camp on the ice because of a possible breakup. Thus, there are many conditions which could abort the mission.

Early in this study, industry was surveyed for new platforms that could operate in the Arctic. The survey turned up the air cushion vehicle which could readily traverse such difficult and varied surfaces as ice, snow, water, and tundra. Bell Aerospace is currently field testing a 25-ton payload flat deck version of the ACV, known as the Voyageur, in the central Canadian Arctic. The flatbed design offers flexibility in configuring the vehicle for multimission operation (e.g., supply, personnel carrier, search and rescue, and scientific field operation). In the latter mission the ACV would be equipped with removable modules comprising working laboratories, housing, and data collection and recording facilities. The manufacturer claims a range of 300 miles for the Voyageur at average cruising speeds of 30 mph for full fuel capacity.

In August 1971, a predecessor model of this craft (the SK5) was engaged in an oceanographic experimental mission 75 miles north of Point Barrow in the Arctic Ocean to prove its feasibility as a data collection platform. The tests successfully pointed up the prospects for utilizing the ACV as an all-season platform and mobile scientific station. As a year-round data collection station for short-term missions, this platform can perform most of the operations now being done at ice island T-3, and with greater maneuverability. The Voyageur can be transported by icebreaker and aircraft to widely separated regions for local deployment. Adequate space, weight, and primary electric power can be provided aboard to make the ACV a mobile command and control center for integrating and coordinating airborne and underwater data collection platform operations. (See Figure 18.)

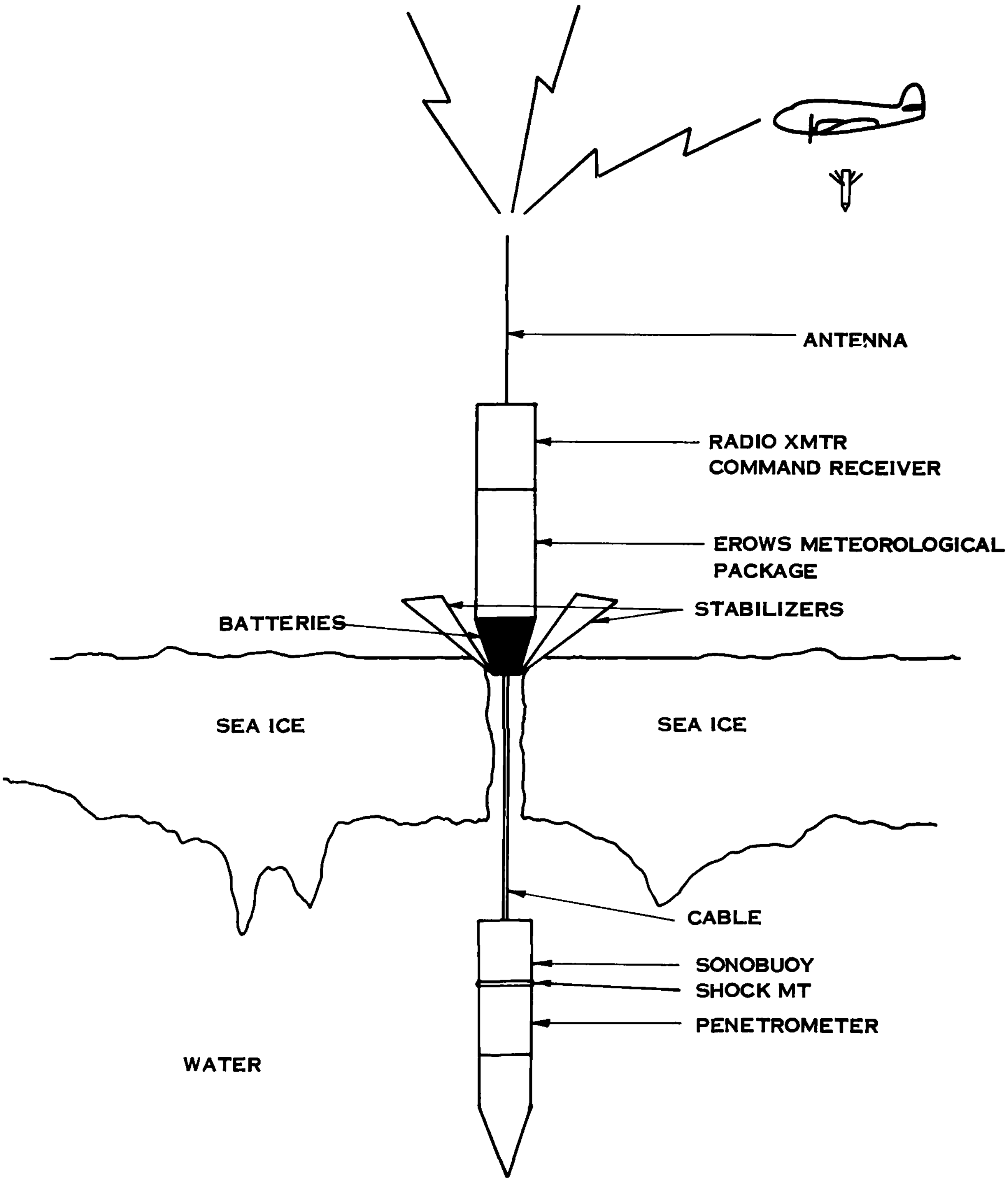


Figure 17 Arctic Air-Droppable Package

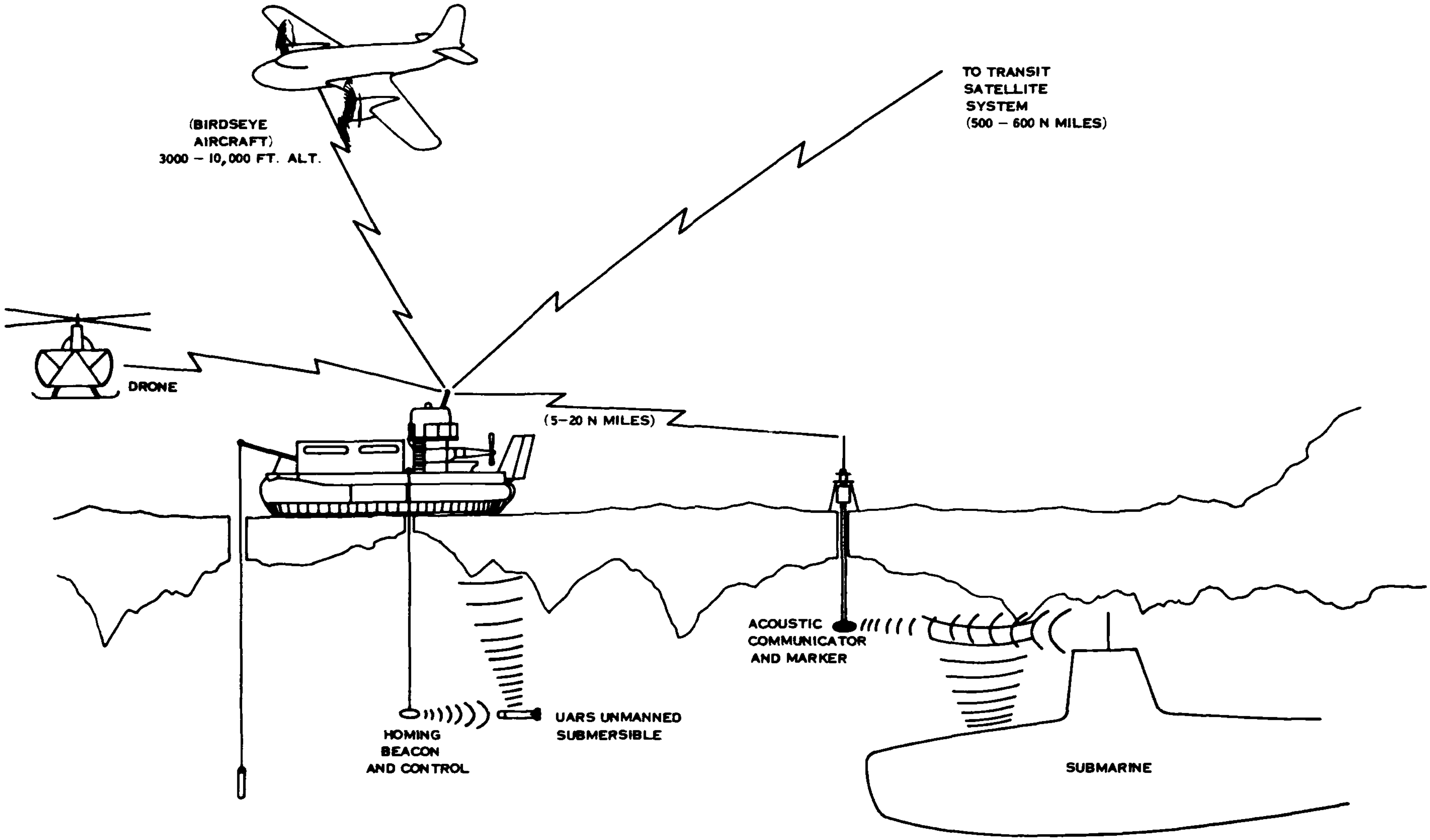


Figure 18 Underwater Arctic Reasearch

Since the ACV can operate year-round in the Arctic, its greatest advantage appears to be for scientific activity. Capital investment figures advanced by Bell Aerospace indicate that a production model Voyageur can be purchased for about $1.3 million. Modifications and new equipment for converting the vehicle to a scientific data collection station would cost another $250,000, making a total investment of $1.55 million. This appears competitive when compared to costs for comparable airborne and marine transports with no relative constraints on all-season operation. The Voyageur can be leased which would be an alternative for acquiring the platform at the lowest capital investment risk.

References

1. Church, J. F. and R. M. Pierce. An Expendable Remote-Operating Weather Station (EROWS). Air Force Cambridge Research Laboratories, Bedford, Mass., Aug. 1971.

2. Hastings, A. D., Jr. Arctic Basin--Location of Climatic (Drift) Stations. Report ETL-TR 71-5, U.S. Army Engineer Topographic Labs, Dec. 1971.

3. Wittmann, W. I. and others. Proposed Arctic Drift Ship Station Study. U.S. Navy Oceanographic Office, Sept. 1961.

SECTION VIII

TECHNICAL CONSIDERATIONS

Quality of Message Transmission and Reception

Successful transmission requires consideration of: transmitter output power, antenna gain, transmission rates, error control, attenuation over the link, signal-to-noise ratios at specific points, modulation and demodulation trade-offs, and the type and degree of ground station processing.

Successful message reception refers to the requirement that the data collection system deliver an accurate reproduction of the data generated by the transmission system. The requirement should be that the probability of receiving at least one accurate message per data platform during a 3-hour period should be at least 0.95 percent. This requirement can be satisfied by (1) receiving the message error free and delivering it to the user without additional ground station processing, or (2) receiving the message with errors and allowing the ground station to correct the message.

In theory, error-free reception may be accomplished by (1) increasing power and amplification levels, and improving channel quality, or (2) requesting repeated transmissions of the same message. Operational constraints and cost generally preclude implementation of a large system with complete error-free transmission and reception.

Error protection may be provided in several ways. A message may be transmitted several times with or without acknowledgment procedures. Either part of the message or the entire message may be encoded for either error detection or forward-error correction. Errors missed by decoding may be corrected by additional processing; e.g., by redundancy, by reasonableness checks, or by manual comparison and modification.

Accurate message reception is primarily determined by: (1) mutual interference due to time and frequency overlap of individual data platform transmissions, or (2) nonmutual interference due to random noise fading and transmitter/receiver malfunctions. The most significant nonmutual interference effect is due to Gaussian or random noise.

The probability of completing a particular transmission without interference is given by the following equation:

$$P(\text{success}) + 1 - \left[1 - \left(1 - \frac{2d}{T}\right)\right]^{NK}$$

where

P = probability of success

d = transmission duration

T = time interval between successive transmissions

N = number of platforms

K = number of independent intervals during which transmissions may occur

Thus, to reduce the probability of mutual interference, you may apply one of the following:

- Reduce the transmission duration (d).
- Increase intertransmission time (T).
- Decrease the number of potentially interfering platforms (N).
- Increase the number of trial intervals (K).

Transmission of the same message in a shorter time implies either an increase in transmitter power (resulting in increased platform costs) or a decrease in transmission quality. More frequent transmissions would require additional average output power (i.e., a higher duty cycle) which would significantly impact on platform cost. The number of platforms and the trial intervals are essentially limited by the number of platforms accommodated by the system. Also, the opportunities for transmission are limited by satellite-platform mutual visibility window durations and frequencies.

Modulation Techniques

Choosing the optimum modulation technique for a high-quality transmission system necessitates an evaluation of the system characteristics of each modulation scheme. Comparison of these techniques are considered: PCM/FM, PCM/AM, PCM/PM, and PAM/FM. Qualitative comparisons of each type are shown in Table VI.

Due to the high signal-to-noise requirements for PCM/AM and PAM/FM, these techniques appear to have limited application. The other modulation schemes can be classified as either narrowband or wideband. PCM/FM is wideband while PCM/PM is narrowband.

The narrowband approach has the following advantages and disadvantages:

- Requires lower transmission power to achieve a given signal-to-noise ratio due to the narrower band width of noise.
- Allows use of frequency diversity to discriminate between interfering transmissions.
- Requires more complex ground receiver design.

TABLE VI

COMPARISON OF MODULATION TECHNIQUES

Factors for Consideration	Modulation Method			
	NB PCM/FM Two-Channel Detector (Noncoherent)	NB PCM/FM Discriminator or Phase Lock (Coherent)	WB PCM/FM Discriminator	PCM/PM (Coherent)
Reliability				
Fading problems	Low	Low	Low	Low
Impulse noise	Low	Low	Low	Medium
Performance				
Input S/N for equal bit rate and BER = 10^{-5}	13.5 dB	12 to 12.9 dB	2.4 dB for m=10 4.8 dB for m=2.5	9.7 dB
Min RF receiver bandwidth	3 BR or 1.5 BR per chan.	1.5 BR (theory) 2 BR (pract)	1.5 df (theory) 2(m+1) df Carson's rule	1.5 BR (theory) 2 BR (pract)
Accuracy limitation	<1%	<1%	<1%	<1%
Complexity				
Amplitude distortion	Low	Low	Low	Low
Delay distortion	Low	Low	Low	Low
Frequency stability	High	High	High	Low
Phase stability	Medium	Medium	Medium	High
Implementation complexity	Medium	Medium	Medium	High

TABLE VI (CONT.)

COMPARISON OF MODULATION TECHNIQUES

Factors for Consideration	Modulation Method				
	PCM/PM (Different Coherent)	PCM/AM (Non-coherent)	PCM/AM (Coherent or VSB AM)	NB PAM/FM (Coherent)	WB PAM/FM (Coherent)
Reliability					
Fading problems	Medium	High	Low	Low	Low
Impulse noise	Medium	Medium	High	Low	Low
Performance					
Input S/N for equal bit rate and BER = 10^{-5}	10.3 dB	18.6 dB	17.6 dB	47.2 to 48.3 dB equiv. to 3 to 8 bit words	15.4-16.7 dB for m=10. 33.5-34.8 dB for m=2.5.
Min RF receiver bandwidth	1.5 BR (theory) 2BR (pract)	1.5 BR	1.5 BR	(1.5-2)X sample rate	1.5df (theory) 2(m+1)df Carsons rule
Accuracy limitation	<1%	<1%	<1%	<1% (≈2%)	<1% (≈2%)
Complexity					
Amplitude distortion	Medium	High	Low	Medium	Medium
Delay distortion	High	Low	High	Medium	Medium
Frequency stability	High	Low	Medium	Medium	Low
Phase stability	Medium	Low	High	Low	Low
Implementation complexity	Medium	Low	High	Low	Low

In contrast, the wideband approach requires a higher bit rate and shorter transmission time to reduce mutual interference probabilities rather than frequency separation. Its advantages are receiver simplicity and availability. Among the disadvantages are (1) requires more transmitter power than the narrowband approach, and (2) may not be easily interfaced with a ground communication channel because of higher bit rates.

Encoding Techniques

Where PCM data transmission systems are used, sensor output pulses or levels are encoded for each sample. A comparison of reliability, performance, and system complexity is given in Table VII for the following encoding techniques:

NRZ-L	RZ (unipolar)	Biphase-M
NRZ-M	RZ (bipolar)	Biphase-S
NRZ-S	Biphase-L	Duo-binary

The reliability characteristics consider data interference effects; i.e., drift problems, intersymbol interference, and error detection. Drift problems refer to the capability of the system to maintain bit synchronization in the presence of long sequences of 1s and 0s. While synchronization might not be a limiting factor in comparing the different encoding formats, it does enable a receiver to maintain bit synchronization in the presence of impluse (or burst) noise from interference effects.

Intersymbol interference refers to errors that can occur from the system's inability of correctly identifying a given bit due to frequency delay distortion effects between adjacent bits. While all the encoding formats would use individual pulse shaping to minimize intersymbol interference, differences in the intersymbol interference could occur due to the different pulse train spectrums. The third factor is error detection capability. While special codes can be used for error detection and correction, some coding formats have inherent error detection properties due to the design sequence of the encoded bits.

Performance characteristics consider (1) RF requirements for wide IF bandwidth, Gaussian noise, and bit error rate, and (2) spectrum bandwidth. In general, the RF power requirements may be considered for regenerated data using either 100 percent or 50 percent integrators in the region where the noise bandwidth is greater than the bit rate. Pulse train spectrum bandwidths along with the frequency uncertainties are important in determining required system bandwidths. Since the Fourier spectrum of the pulse train is directly proportional to the bit rate, the spectrum bandwidths are proportional to the bit rates or the average number of zero crossings per second.

Complexity considerations include dc restoration problems and self-clocking system characteristics. DC voltage components occur in the transmitted spectrum of some code formats. As a result, this factor is important

TABLE VII

COMPARISON OF ENCODING TECHNIQUES

Code Format	Reliability			Performance		Complexity	
	Drift Problems	Inter-symbol Inter-ference Problems	Error Detection Properties	RF Power (Same Wide IF Bandwidth, Gaussian Noise, and Ber)	Spectrum Bandwidth	Problem with DC Restor-ation	Self-clocking System
NRZ-L	Yes	No	No	Standard 0dB (100% Int.) +3dB (50% Int.)	Equal to Bit Rate	Yes	No
NRZ-M	Yes	No	No	Standard 0dB (100% Int.) +3dB (50% Int.)	Equal to Bit Rate	Yes	No
NRZ-S	Yes	No	No	Standard 0dB (100% Int.) +3dB (50% Int.)	Equal to Bit Rate	Yes	No
RZ (Uni-polar)	Partial	Some	No	More than NRZ-L +3dB (100% Int.)	2 Times Bit Rate	Yes	Partial
RZ (Bipolar)	No	No	Yes	More than NRZ-L +3dB (100% Int.)	2 Times Bit Rate	Yes	Yes
Biphase-L	No	Some	Yes (50% Int.) Yes (100% Int.)	Approx. Equal NRZ-L 0dB (100% Int.,N>0.0BR) -3dB (100% Int.,N>0.5 BR)	2 Times Bit Rate	No	Yes
Biphase-M	No	Some	No	Approx. Equal NRZ-L 0dB (100% Int.,N>0.0BR) -3dB (100% Int.,N>0.5BR)	2 Times Bit Rate	No	Yes
Biphase-S	No	Some	No	Approx. Equal NRZ-L 0dB (100% Int.,N>0.0BR) -3dB (100% Int.,N>0.5BR)	2 Times	No	Yes
Dro-binary	Yes	No	Yes	More Than NRZ-L +3dB (100% Int.)	1/2 Bit Rate	Yes	No

in selecting an encoding technique, since dc amplification and restoration are difficult in reconstructing the pulses and can lead to significant errors in establishing the slicing voltage interval for bit detection.

The self-clocking characteristics refer to the ability of the code format to supply bit timing to phase lock loops or resonant circuits. Alternatively, the bit timing required to reconstruct the pulses can be obtained by using an accurate clock, by using a pilot signal, or by setting the bit period equal to an integral number of carrier cycles and later counting down to obtain the bit frequency. The accurate clock method has frequency stability problems and may not be suitable. The pilot frequency method requires a separate synchronizing channel which results in extra equipment and transmitter carrier power. Bit timing by the countdown method is difficult to implement.

In summary, major items of concern in selecting the proper encoding method are bandwidth utilization, number of states required, and self-clocking characteristics.

System Design Accuracy

The accuracy of the data collection system is limited by the accuracy of the input sensors and the transmission system. Improving the accuracy of the transmission system cannot reduce the overall error below the sensor error: conversely, reducing sensor errors will not reduce the overall error below that of the transmission system. The data collection system must be designed to ensure that the transmission system does not significantly degrade the accuracy of the sensor data. Transducer or sensor inaccuracies vary over a large range, from less than 1 percent for laboratory sensors to as high as 20 percent for field sensors. It is expected that many environmental transducers for field use will actually exhibit inaccuracies of more than 5 percent of their full-scale range.

The transmission system should be designed for an accuracy of 3 percent or better so that the measurement inaccuracy is primarily that of the sensor. A 3 percent transmission accuracy will probably satisfy most potential users of the system. Higher accuracy increases costs.

In a system where accuracies of around 10 percent are acceptable, PAM data encoding costs less and is easier to implement. Where accuracies of greater than 5 to 7 percent are required, PCM is cheaper. This is due to the linearity required of the analog circuit to achieve high system accuracies. In a PCM system, the analog circuit is restricted to the analog multiplexer sample-and-hold circuit and to the analog-to-digital converter because these circuits are impacted by the increased accuracy requirements. A PAM system shares all of the above circuits except the analog-to-digital encoder, and require the same accuracies and linearities in the modulator and transmitter. In the PCM system, once the amplitude has been encoded in digital form, linearity is no longer important. In addition, data in digital form can easily be encoded for error detection and correction to reduce the effects of noise in the transmission link upon data accuracy. Thus, PCM encoding is favored for the data collection system.

Selection of the number of levels each data sample is encoded is determined primarily by system accuracy requirements. The error can be separated into two components--analog and digital (quantizing) errors. The quantizing error is determined by the number of bits or levels that the data sample is encoded to. The analog error is determined by the data rate of change, the data aperture size, the source impedance of the sensors, multiplexer errors, sample-and-hold circuit errors, and encoder errors other than the quantizing error. A PCM system may be designed so that the system error is due primarily to the analog errors. The cost of reducing the total error is also almost entirely the cost of reducing the analog error. The cost of adding one bit to each register and of increasing the bit rate to reduce the digital error is small, but the reduction of analog errors in a system that must operate over a broad temperature range can be significant.

The number of levels in the encoder should be chosen so that system accuracy as determined by the analog error is not significantly reduced. Peak error due to quantization is given by:

$$E_{max} = \pm \frac{1}{2} \frac{1}{N}$$

where N, the number of encoding levels, is given by 2^b-1, with b being the number of bits used to represent each sample.

If the input amplitude probability is uniformly distributed, the rms quantizing error is given by:

$$E_{rms} = \frac{E_{max}}{\sqrt{3}}$$

$$E_{rms} = \frac{1}{2 \sqrt{3} \ (2^b-1)}$$

Applying various values of b yields the following tabulation:

b	E_{max}	E_{rms}
4	±3.33%	1.92%
5	±1.61%	0.93%
6	±0.79%	0.46%
7	±0.39%	0.23%
8	±0.20%	0.11%

For a system accuracy design goal, a 6-bit representation for each data word appears to be good selection in order to keep the digital error contribution to the overall error budget small. This permits the rms analog error to be as high as 2.5 percent while still achieving the system accuracy goal.

Antenna Patterns

In satellite relay systems, ground platform transmitter antenna patterns seriously influence the performance of the entire data collection system. Interference studies on existing polar-orbiting systems show that low minimum grazing angles are required to increase the duration of the time window in which the platform, satellite, and ground station are mutually visible, thus increasing the number of transmissions during that time since this increases the overall probability of success. It is difficult to establish a reliable link at low grazing angles. In addition, antenna gain tends to decrease at low angles due to ground plane reflector limitations. At the same time, path losses are greater due to the increased slant range to the satellite. A minimum grazing angle of approximately 20° is considered acceptable to yield a high probability of successful message transmission.

References

1. Stiltz, H. L. (Ed). Aerospace Telemetry. Vol. 1 and 2, Prentice Hall, 1961 and 1966.

2. Signal Margin Calculations for Spacecraft Links. NASA Goddard Space Flight Center, June 1971.

3. Earth Resources Technology Satellite Data Collection System Design Studies. NASA Goddard Space Flight Center, Feb. 1970.

4. Nichols and Rausch. Radio Telemetry (2nd Edition). John Wiley and Sons, Aug. 1960.

5. Telemetry Standards (Revised). IRCC Telemetry Working Group. Doc 106-71, Published by Range Commanders Council, White Sands Missile Range, Jan. 1971.

SECTION IX

DATA MANAGEMENT

At present, practices for handling the collection of field data are chosen by the scientist who undertakes the work. In the future, the accummulation and integration of field data from the Arctic will require an integrated data management effort.

Experience from a large-scale data program (BOMEX--Barbados Oceanographic and Meteorological Experiment) points up the urgent requirement for real-time monitoring of data during field acquisition and for reducing and validating the data quickly at the end of the program. To achieve these goals, the following actions are required for each large-scale program:

- Assignment of the data management function.
- Plans for selective data collection.
- Performance of data system simulations before undertaking the field work.
- Maintenance of quality control so that inaccurate and superfluous data can be detected and removed from the system.

Figure 19 depicts the structure and interaction of data management as might be applied to a manned arctic scientific project. The project data manager, through a data requirements and selection committee comprised of program staff scientists and data processor modeling experts, will determine the type and number of parameters to be recorded in the data collection system. At a data center, which will serve all projects of the Arctic, a monitoring facility will be available for selective sampling, recording, and preprocessing the data during the acquisition period. The data will be recorded on digital magnetic tapes for interface with the central processor. Real-time monitoring of a portion of the data will serve to indicate which systems are functioning and to ensure that data are being received and recorded. Also, if large quantities of data are inferior, they can be spotted and discontinued. A limited amount of data processing and evaluation will be performed, and the results will be fed to the investigators via the scientific program office. Turn-around time will be short so that the information can reach the investigator while he is still in the field and thus enable him to assess the operation of his experiment. Analyzing this data during the early acquisition stages of the experiment should uncover many major defects.

A data bank will be located at the data center for data storage and retrieval. Data entering the system during the experiment will be stored in the data bank. Finalized data inputs in the form of data reports will enter the archives at the completion of analysis of field results. The archives will be a depository for all data which was not accessed into the data collection system either because there was no immediate need for the data or because the data could not be interfaced with the recording facility.

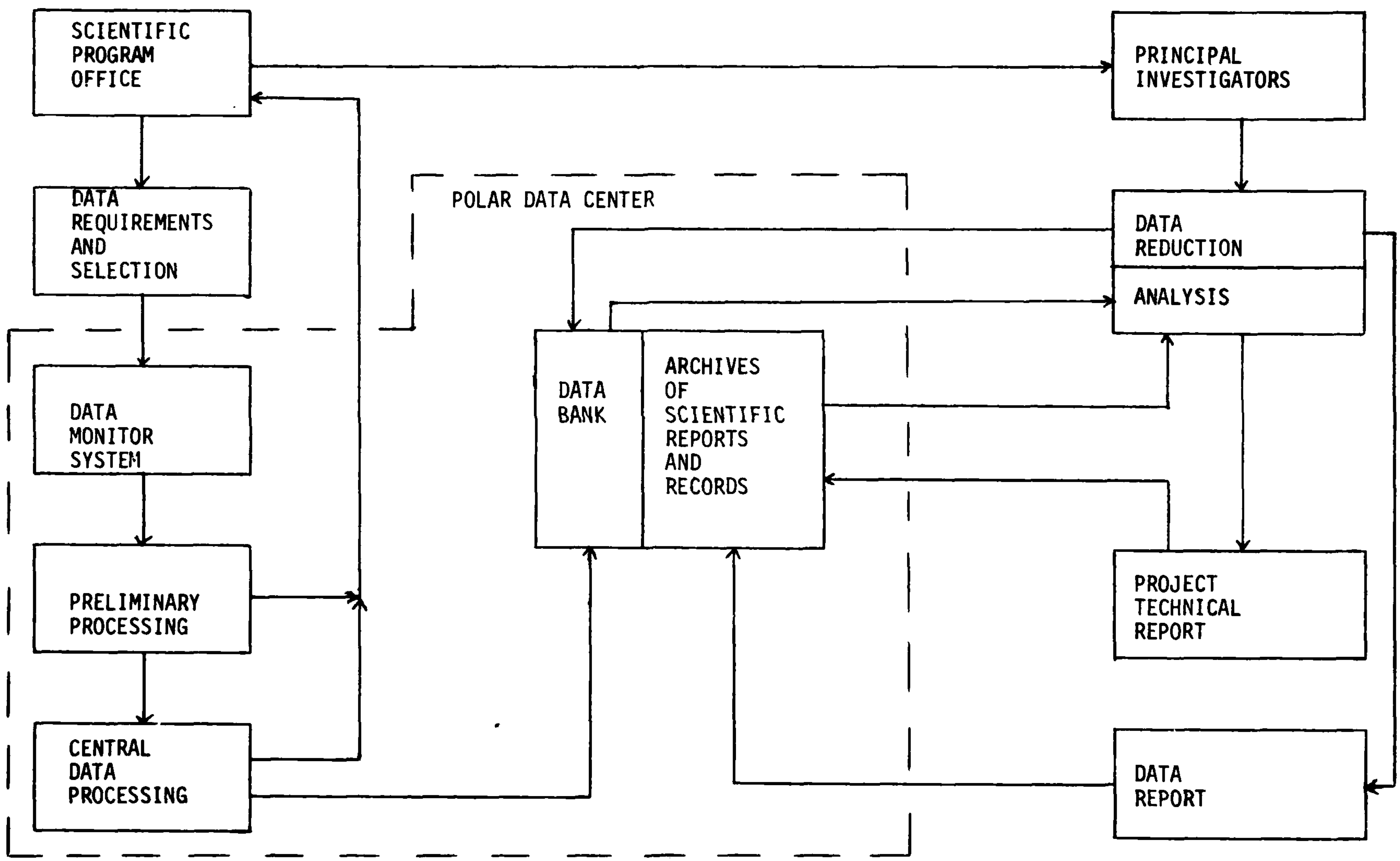


Figure 19. Interaction Diagram of Scientific Data Management System

Facilities will also be available at the data center to sample, monitor, and process data acquired from unmanned data stations. Detected errors, low signal levels, and inoperative sensors will be investigated by data center personnel, who will correct the malfunction or prevent inaccurate data from entering the data bank.

The data manager is responsible for the operation of the data center. His office will generate guidelines and procedures for accessing and retrieving data entering or leaving the storage facility.

The minimum cost to implement a polar data control center near Anchorage or Fairbanks, Alaska is estimated at $1.5 million.

References

1. Holland and Williams. Planning for Large-Scale Observational Programs. Bulletin of Amer. Meteorological Society, Vol. 52., No. 9, pp 850-856, 1971.

2. Narrow, B. Satellite Telemetry Data Processing at Goddard Space Flight Center. NASA Goddard Space Center, July 1966.

3. Keville, B. F. Considerations in Establishing a Computer Archive for Ice Data. NAVOCEANO, Mar. 1971.

4. Bomex Bulletin No. 4. Bomex Project Office, Interagency Planning Group, Rockville, Md., May 1969.

5. Telemetry Standards (Revised). Telemetry Working Group Document 106-71, Published by Range Commanders Council, White Sands Missile Range, Jan. 1971.

APPENDIX A

ARCTIC DATA COLLECTION SYSTEM STUDY SURVEY

TABLE A-I

CONTACTS AND INTERVIEWS

Date	Scientist	Agency	Industry	Status
7/6/71			Mr. J. Meyers Submarine Signal Div. Raytheon Company Portsmouth, R.I.	Completed
7/7/71		Dr. A. Assur CRREL Hanover, N.H.		Completed
7/7/71		Austin Kovacs CRREL Hanover, N.H.		Completed
7/20/71	*Dr. L. Coachman University of Washington Seattle, Wash.			Completed
7/20/71	*Dr. R. Muench University of Alaska College, Alas.			Completed
6/22/71		Mr. W. Wittmann NAVOCEANO Washington, D.C.		
7/21/71	*Dr. F. Muller Swiss Federal Institute of Technology Zurich, Switzerland			Completed
7/20/71		*Mr. T. Harwood Defence Research Board Ottawa, Canada		Completed

* Washington, D.C. interviews--Baffin Bay/North Water Project.

TABLE A-I (Cont.)

CONTACTS AND INTERVIEWS

Date	Scientist	Agency	Industry	Status
7/20/71	*Dr. F. I. Badgley University of Washington Seattle, Wash.			Completed
6/11/71	*Dr. E. F. Roots Polar Continental Shelf Project AIDJEX Ottawa, Canada			Completed
7/20/71	*Dr. M. Dunbar McGill University Montreal, Canada			Completed
6/11/71	*Dr. A. E. Molloy Arctic Submarine Laboratory San Diego, Calif.			Completed
7/20/71	*Capt. D. C. Nutt North Water Project Hanover, N.H.			Completed
7/9/71		Mr. D. Loftus and Mr. V. Myrick Telecommunications Branch, DOC Ottawa, Canada		Completed
7/9/72		Mr. O. S. Roscoe National Research Council Ottawa, Canada		Completed
7/13/71		Mr. David Scull Transit Project Office, Navy Washington, D.C.		Completed

TABLE A-I (Cont.)

CONTACTS AND INTERVIEWS

Date	Scientist	Agency	Industry	Status
6/30/71		Mr. C. Cote and Mr. L. Roach NIMBUS/IRLS Office, NASA Washington, D.C.		Completed
7/29/71		Mr. J. Huffman Office of Polar Programs, NSF Washington, D.C.		
7/22/71			Mr. H. C. Baker Manhattan Project, Humble Oil Co. Houston, Tex.	

TABLE A-II

VISITS AND CONTACTS

Date	Company	Location	Contact	Subject
8/15/71	Texas Instruments	Dallas, Tex.	Strickland	Sensors
8/17-18/71	*Marine Technology Symposium	Washington, D.C.	--	Sensor technology Data handling
8/25/71	*IEEE Geosciences Electronics Conf.	Washington, D.C.	--	Sensor technology
8/26/71	Lenkurt Electric	Washington, D.C.	J. Barber	Microwave radio
9/2/71	Raytheon-Submarine Signal Division	Portsmouth, N.H.	J. Myers	Sensors
9/7/71	*AFCRL	Hanscom AFB Bedford, Mass.	Col. Church EROWS	Air drop weather sensor
9/7/71	*AFCRL	Hanscom AFB Bedford, Mass.	Dr. J. Whelan R. Commier S. Silverman	Aurora and PCA Anomolies Geopole program
9/14/71	Atlantic Research Corp.	Washington, D.C.	J. Imber	A/D conversion data multiplexing
9/16/71	NAVOCEANO	NLR Anacostia, Md.	W. Wittmann	Sea ice reporting
9/24/71	*Navalex	Washington, D.C.	Ebkin	HF communications
9/27/71	*Lamont-Doherty	Palisades, N.Y.	Dr. K. Hunkins	Ocean data sensing AIDJEX IRLS experiments
9/28/71	*General Electric	Valley Forge, Pa.	B. Clemson	Transitel (Apollo TV ship) terminal

*Visited.

TABLE A-II (Cont.)

VISITS AND CONTACTS

Date	Company	Location	Contact	Subject
9/30/71	*NSF	Washington, D.C.	Col. J. O. Fletcher	NSF data requirements
10/4/71	*NOAA Air-weather SVC	Silver Spring, Md.	J. Neilon	NOAA communication system
10/5/71	Alden Recording	Westboro, Mass.	M. Stewart	Sensors
10/5/71	Endeco	Marion, Mass.	W. Barnes	Sensors
10/5/71	3M	Camarillo, Cal.	V. Lindquist	Recorders
10/5/71	*NOAA BOMAP-CEDDA	Rockville, Md.	Dr. Holland S. Williams	Data management Digital data processing
10/6/71	*NASA ATS F/G	Goddard Space Flight Center, Md.	G. Bullock	Satellite relay
10/6/71	*NASA ERTS/Nimbus program	Goddard Space Flight Center, Md.	W. Scull E. Painter	Satellite acquisition
10/13/71	AIDJEX Project	Seattle, Wash.	H. Lahore	Sensors/data management
10/14/71	*NSF	Washington, D.C.	J. Huffman Dr. Sites	UGO-data management planning
10/27/71	General Electric Space Center	Arlington, Va.	--	DCS-Alaska comm. carrier circuits

TABLE A-II (Cont.)

VISITS AND CONTACTS

Date	Company	Location	Contact	Subject
11/2/71	Dept. of Energy, Mines & Resources	Hershey, Pa.	F. Roots	Concept briefing
	Institute of Marine & Atmospheric Science	Hershey, Pa.	H. Bader	Concept briefing
	AIDJEX Project	Hershey, Pa.	N. Untersteiner	Concept briefing
	USNUSW, San Diego	Hershey, Pa.	A. Molloy	Concept briefing
	NAVOCEANO	Hershey, Pa.	W. Wittmann	Concept briefing
	Naval Underwater Systems Center, R.I.	Hershey, Pa.	W. Birch	Interview
	G.M., Delco Div.	Hershey, Pa.	B. Buck	Interview
11/4/71	CRREL, N.H.	Hershey, Pa.	R. Atkins	Interview
12/3/71	Navy Transit	--	D. Scull	Navy transit
12/6/71	Navy Transit	--	D. Klein	Navy sensor repair facility
12/8/71	CDC/AINA	--	R. Lillistrand	Data reduction

TABLE A-II

VISITS AND SENSORS

Date	Company	Location	Contact	Subject
1/11/72	NASA ERTS Project Office	Goddard Space Flight Center, Md.	E. Painter	Data collection
1/11/72	NASA TWERLE Program Office	Goddard Space Flight Center, Md.	M. Friedman	Remote sensing satellites
1/14/72	NSF	Washington, D.C.	J. Huffman	Electrical power sources
1/21/72	Navy Facility Engineering Center	--	T. Fleming	Radioisotope power sources
1/28/72	Naval Fleet Weather	Suitland, Md.	Lt. Cdr. Dehn	Sea ice reports